



**BRITISH COLUMBIA
ACID MINE DRAINAGE
TASK FORCE**

Canada



**SHOTCRETE APPLICATION OF
CEMENTITIOUS SEALANT
MATERIALS FOR
ACID ROCK DRAINAGE CONTROL**

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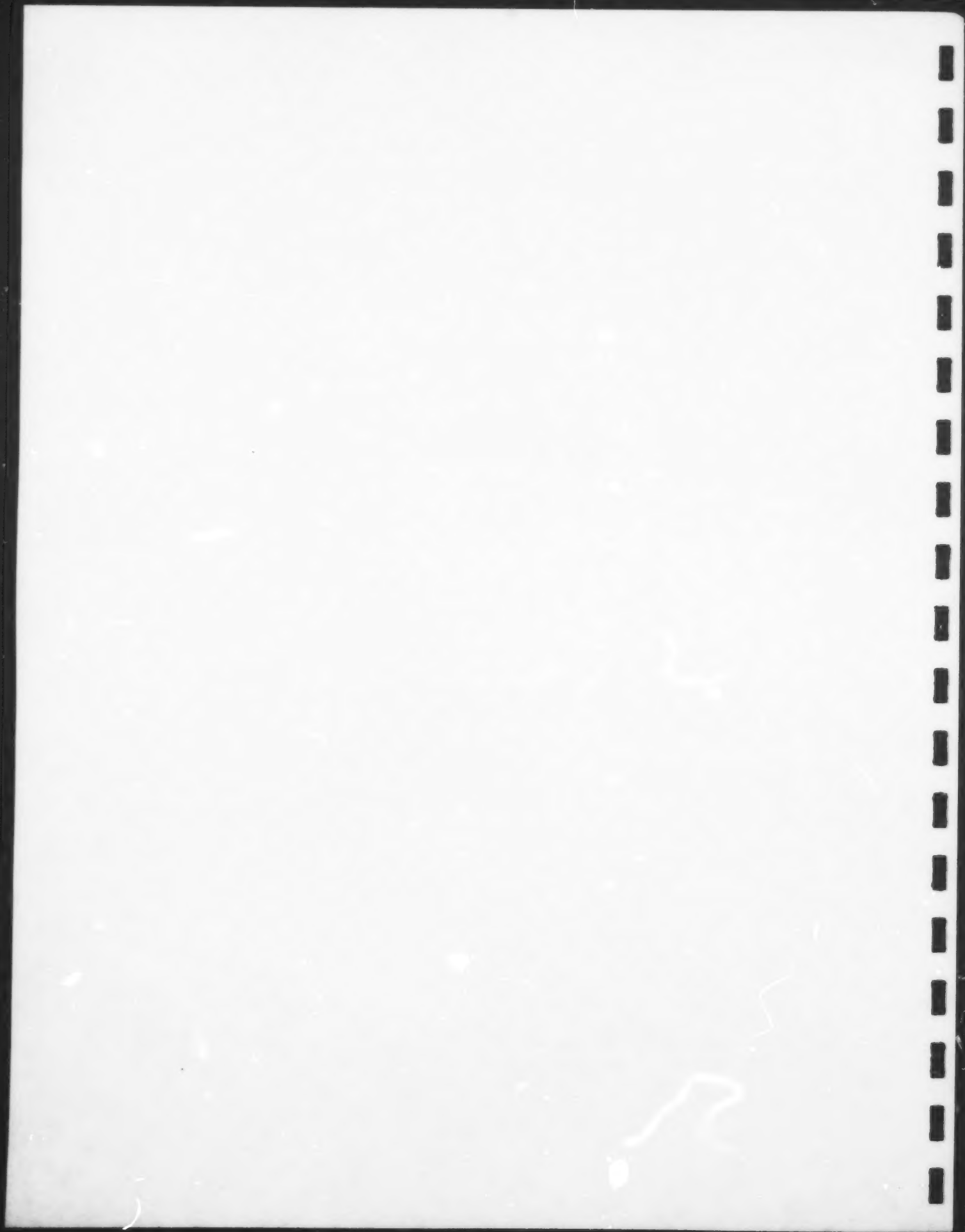
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SUMMARY

This report describes the testing program to incorporate waste mine tailings in a shotcrete mix for application on waste rock dumps to control acid mine drainage (AMD).

Initial laboratory trial mixes were performed to maximize the usage of waste materials. Testing has shown that mixtures incorporating up to 100% of mine tailings as aggregate can be solidified into homogenous matrices. Ductility in the structure, to withstand local settlement, was achieved using polypropylene fibres as reinforcement in the mixes. Due to the low water/cement ratios required to achieve the minimum design compressive strength, additives were included in the design to make the mixtures more workable. Fly ash was incorporated in the mixtures to lower the material cost. It was found that the minimum cementitious content in the mixes should not be lower than 25 %.

Based on testing of the laboratory trial mixtures, proportions of materials were modified for the shotcrete test panels. Five mixtures were shot using the wet mix shotcrete process. The designed mixtures were found to be pumpable and adhered to vertical surfaces. Testing of the panels showed that mixtures with quantities of mine tailings in excess of 40% as aggregate, will adversely affect the compressive strength of the material.

This study has shown that a fibre reinforced solidified cementitious cover can be applied to sloping waste rock surfaces using shotcreting methods. It is therefore recommended that this material be tested in a pilot scale model to evaluate the effectiveness of a cementitious surface sealant to restrict acid generation with the rock pile.

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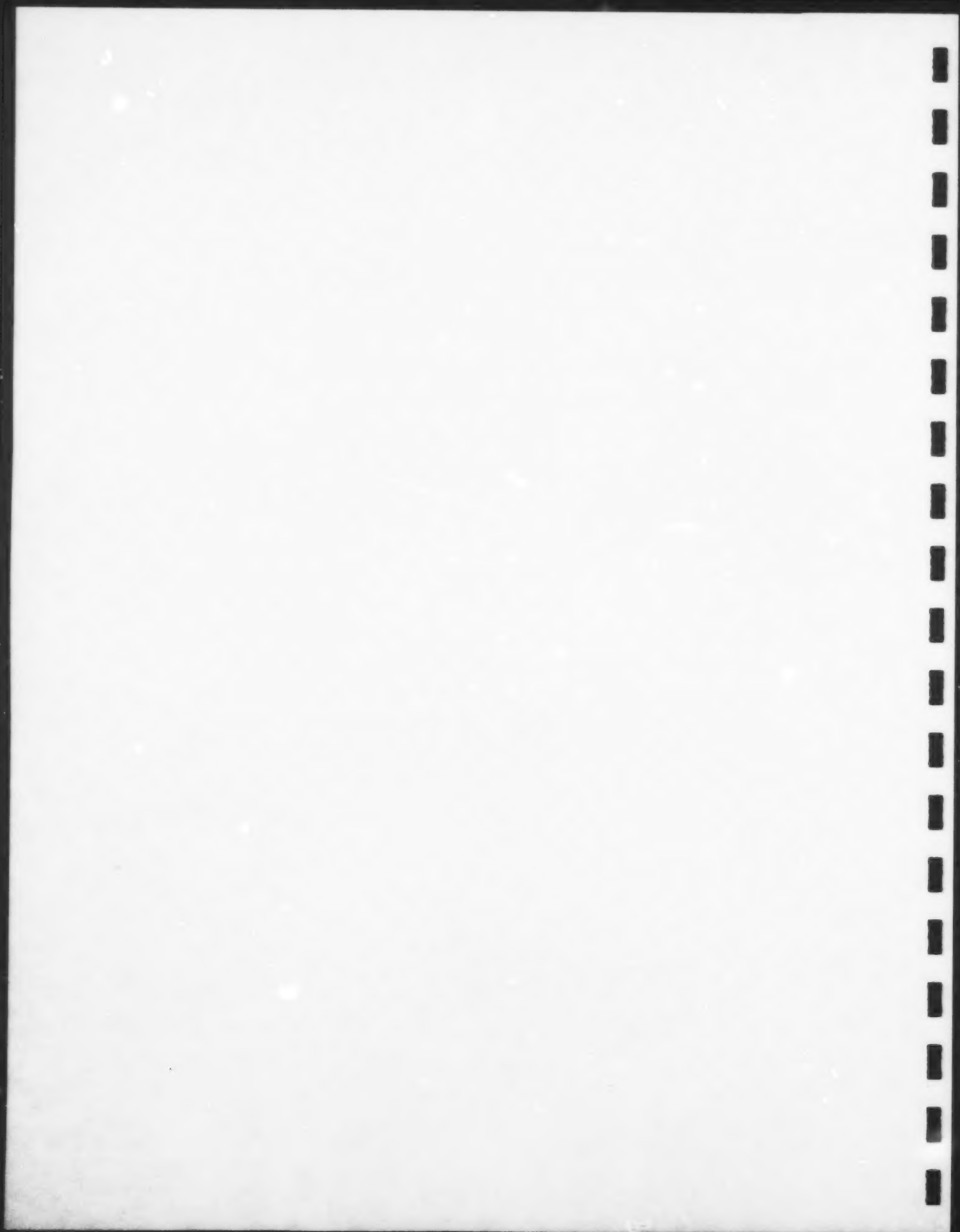
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1.0 INTRODUCTION

Recent studies by Northwest Geochem¹ evaluated the efficacy of solidified mixtures containing cement, water treatment sludge, mine tailings, and sand for use both as a surface sealant and a grouting matrix for the control of acid rock drainage at the Westmin Myra Falls site. Laboratory results indicated that the solidified cementitious mixtures developed can achieve good compressive strengths, workability, and durability. Field scale trials have further evaluated the durability and weathering of the solidified mixtures and demonstrated that the metal levels in the sealant surface runoff do not exceed effluent criteria. However, the mixtures to date have been designed as a placed cement product. Field trials indicate that this method of application has serious drawbacks when used to cover sloping rock faces due to the thickness of the application, difficulty in access, and large areas to be covered.

An alternative application technique to the poured approach is using shotcrete which can place concrete on steep rock faces and sloping waste rock dumps at controlled thicknesses. Shotcrete is mortar or concrete shot into place by means of compressed air. The shotcrete has to have a relatively dry consistency so that the material can support itself in any position; at the same time, the mix has to be wet enough to obtain compaction and adhere to the surface. The high velocity with which the concrete is shot also gives shotcrete a high bond strength.

The purpose of this study is to determine how to optimize the use of mine wastes such as coarse tailings in a shotcrete mix which can be applied to vertical or sloped rock faces.

The research program consisted of the following:

- Design of the shotcrete mix to maximize the use of mine tailings.

- Trial mixes to investigate the effects of the addition of waste materials, admixtures, and fibres to the shotcrete and to evaluate material properties.
- A pilot scale test in which test panels of the shotcrete were shot.
- Testing of the shotcrete panels in accordance to established ASTM and CSA procedures.

2.0 MIX DESIGN

Because of the potentially large areas at the mine site to be covered by the solidified mine tailings, cost was a major consideration in the mix design. The use of mine tailings in the mix was maximized because of the high cost of importing materials to the site. Other important factors incorporated into the design of the cementitious mixtures were as follows:

- The mix must have good workability so that it can be easily pumped.
- The solidified mix must be durable.
- A reasonable compressive strength should be achieved but a high compressive strength is not critical.
- The hardened shotcrete should exhibit good ductility in order to withstand any local settlement in the rock slope.

2.1 Materials

The characterization test results of the materials used in this research program are listed in Appendix A

2.1.1 Aggregates

In conventional shotcrete mixes the aggregate should comply with the requirements of ASTM C33 for grading and quality of aggregates for use in concrete. Gradation No. 1 from ASTM C33 is plotted in Figure 1 along with the gradations for concrete, sand, gravel, tailings, and a blend of sand and gravel. Westmin coarse tailings consist primarily of fine grained sand sizes while the fine tailings are mostly of silt size. It has been shown that gradations consisting of finer materials than a fine grained sand result in solidified materials with a high drying shrinkage, therefore, it was decided to use only the coarse tailings in this testing program.

2.1.2 Cementitious Materials

The cementitious materials used in this program were portland cement and fly ash. Type 10 portland cement was used.

Recent studies^{2,3,4} have shown that high volumes of fly ash can be used successfully in shotcrete applications. The advantages of incorporating fly ash into the cementitious materials are:

- Lower cost (fly ash is a waste by-product from thermal power generation); and
- Lower heat of hydration in the mix thus reducing the potential for cracking.

A Class F fly ash was used in this study. The composition is shown in Appendix A.

2.1.3 Fibres

A major concern in the placement of solidified cementitious materials over a large area is the potential for cracking due to local settlement and shrinkage during curing. The addition of polypropylene synthetic fibres to the mix will inhibit the cracking and increase the "toughness" of the solidified material.

A 38 mm polypropylene mesh type fibre from Fibermesh was used at a dosage rate of 5 kg/m³. The fibre works without affecting the chemical hydration of the cement. Its action is purely mechanical and should be compatible with all mixes and admixtures. It cannot rust, is non-corrosive and is alkali resistant.

2.1.4 Additives

Freeze thaw resistance in concrete is highly dependent on the amount of entrained air in the mix. The optimum air content in most mixes ranges from approximately 5 to 10%. An air entrainment additive, DARAVAIR, was used at a dosage of 200 ml per 100 kg to increase the air content to the optimum range.

The water to cementitious ratio was kept constant in this study. The water cement ratio used, 0.38, is low resulting in a stiff mix which may be hard to pump. To improve the workability of the mix a superplasticizer, DARACHEM, was used at a dosage rate of 450 ml per 100 kg.

3.0 LABORATORY TRIAL MIXES

3.1 Mix Proportions

Preliminary trial mixes were performed in the laboratory in order to assess the workability and mechanical properties of concrete with various tailing content. The five mixes chosen for laboratory testing are listed in Table 1. The tailing contents in these mixes varied between 40 to 100% of the total aggregate. The gradations of the blended

aggregate in the different mixes are shown in Figure 2. The water/cementitious materials (cement+flyash) ratio was kept constant at 0.38 for all the mixes.

3.2 Mix Procedure

Batching of the trial mixes was carried out using a rotating drum mixer. Each mix was approximately 0.042 m³ in volume. The sequence of mixing was as follows:

1. Proportion the materials by weight
2. Place sand and gravel in mixer
3. Place tailings in mixer
4. Add 1/3 water
5. Add fly ash and cement
6. Add remaining water
7. Add admixtures
8. Measure air & slump
9. Add fibres
10. Measure air & slump again
11. Cast test specimens

The specimens were consolidated on a vibrating table in order to simulate the placement using shotcrete.

3.3 Test Results of Laboratory Mixtures

3.3.1 Properties of Fresh Concrete

No major problems were encountered during mixing of the five test mixtures. The fibres were well dispersed into the cement matrix and did not exhibit any clustering. Mix C was the only mixture that exhibited any bleeding after consolidation. Properties of the fresh concrete are summarized in Table 2.

3.3.2 Compressive Strength

Cylinders were prepared for compressive strength testing at 7, 28, and 91 days. The cylinder dimensions were 100 mm in diameter and 200 mm in length. The results are tabulated in Table 3. Mixes A, B, D, and E all had 28 day strengths greater than 10 MPa. Mix E contained less cementitious materials and thus exhibited lower strength. Due to the addition of fly ash, there was a strength gain at 91 days. The compressive strengths obtained in these mixes were reasonably good considering the high usage of very fine aggregates. The solidified material is to be used as a surface sealant and thus high compressive strength is not critical. The complete testing details are shown in Appendix B.

3.3.3 Toughness

Toughness index tests were performed in accordance to ASTM C1018, "Standard Test for Flexural Toughness and First-Crack Strength of Fibre-Reinforced Concrete (Using Beam with Third Point Loading)". This test was carried out on an Instron Dynamic Material Testing System (Model 1333). The purpose of this test is to determine if the mixtures are classified as elastic-plastic materials. The definition of toughness indices is described schematically in Figure 3.

The dimensions of the test beams were 100 mm x 100 mm x 350 mm. The span length used for third point loading was 300 mm. The results of the toughness tests are shown in Table 4 along with the flexural strengths. Although the flexural strengths are low, it can be seen from the high toughness indices that the materials are considered to be elastic-plastic. The load deflection curves for these tests are shown in Appendix C. Note that after cracking has occurred, the load is still sustained as the beam continues to deflect. The fibres give the structure ductility as compared with plain concrete where the load will drop to zero. Figure 4 shows a typical test specimen after a crack has developed.

4.0 SHOTCRETE TEST PANELS

A pilot scale test was performed in which test panels were produced using shotcrete containing various tailings contents. This scale of testing is important to establish that the properties of the shotcrete are consistent with the mixes placed by conventional concrete consolidation methods.

The shotcrete test panels were shot on the premises of Terracrete Systems Ltd. on December 7, 1990.

4.1 Equipment

The shotcrete was applied using the wet mix process. This process consists of the following steps:

1. All the materials are thoroughly mixed.
2. The concrete is placed into the chamber of the delivery equipment.
3. The mixture is metered into the delivery hose and moved by displacement to a nozzle. A schematic of the pumping equipment is shown in Figure 5.
4. Additional air is injected at the nozzle to increase velocity and improve gunning pattern.
5. The concrete is jetted from the nozzle at high velocity onto the surface to be shotcreted.

Equipment:

- Wet mix nozzle (see Figure 6);
- Diesel powered Thompson double piston shotcrete pump (see Figure 7);
- 2" ID delivery hose;
- 375 CFM air compressor; and
- Rotary drum mixer.

4.2 Application

One m² plywood panels were constructed in which to shoot the shotcrete. These relatively small panels can be easily moved after initial cure and dissected for testing. The average thickness of the panel is 100 mm. Two batches of each mix design were required to fill the hopper of the pump (see Figure 8). The total volume for each mix was approximately 0.33 m³.

Five different mixes similar to the laboratory trial mixes were batched in the drum mixer. The proportions of materials used in the mixes are shown in Table 5. Samples A1 to E1 were all designed with a water/cement ratio of 0.38. However, Mix A1 was found to have a very high slump resulting in a very wet mix and the mixture could not be shot onto a vertical surface without sloughing. The panel was then laid horizontal and the shotcrete was successfully placed. The wet shotcrete panel mix likely resulted from an increased water/cement ratio. In the laboratory trial mixes, the moisture content of the sand was measured to be 3.3% while the sand used in the shotcrete mixes was measured to be 7.8%. In the subsequent mixes, the amount of mixing water was reduced in order to maintain a 0.38 water/cement ratio.

Shotcrete mixes B1 to E1 were applied to vertical panels in order to simulate a worst case situation. Figure 9 shows the operator applying a mix to the test panels. Figure 10 shows the test panels after shooting was complete. The mixes were quite cohesive and adhered to the vertical surface without sloughing.

4.3 Test Results of Shotcrete Panels

The shotcrete panels were brought back to Powertech Labs and placed into a humidity chamber for curing. Testing was conducted on samples cut from these panels.

4.3.1 Compressive Strength

Concrete cylinders 75 mm in diameter were cored from the shotcrete panels. The length of these cylinders varied depending on the thickness of the panel. The resulting strengths were corrected for length in accordance to ASTM C42. The test results are shown in Appendix B and summarized in Table 6.

4.3.2 Flexural Toughness

Concrete beams 100 mm x 100 mm x 350 mm were cut from the shotcrete panels. Tests were performed on samples obtained after 7 days and 28 days curing. The results are summarized in Tables 7 and 8. The load deflection curves are shown in Appendix C.

4.3.3 Air Content

The air content of the hardened shotcrete samples were determined in accordance to ASTM C457 "Microscopic Determination of Air-Void Content and Parameters of the Air Void System in Hardened Concrete". Sections of 100 mm diameter were polished until the surfaces were suitable for examination. Table 9 summarizes the air void content of the shotcrete samples.

4.3.4 Absorption After Boiling and Permeable Voids

The absorption after boiling, volume of permeable voids, and bulk relative density of the five shotcrete mixes were determined in accordance to ASTM C642. 75 mm x 75 mm x 75 mm cubes were cut from the shotcrete panels for testing. The results are shown in Table 10.

4.3.5 Permeability

The water permeability of the shotcrete samples were determined using a high pressure method described by Hope and Malhorta⁵. The sample dimensions were 75 mm in diameter and 25 mm thick. A differential water pressure of 350 kPa

was applied across the thickness of the samples. The water flow was measured using a buret. The permeability values are listed in Table 11.

5.0 DISCUSSION

The laboratory and test panel shotcrete studies were conducted to evaluate material and engineering properties of cementitious mixtures which incorporated mine tailings as an aggregate. The use of fly ash and polypropylene fibers in the cementitious mixture was also evaluated. The discussion of testing results will focus on the following physical characteristics which influence the quality of the shotcrete mixtures for use as a surface sealant for ARD control:

- Compressive strength;
- Flexural properties;
- Permeability; and
- Durability.

5.1 Compressive Strength

In conventional construction applications such as walls, buildings and swimming pools, shotcrete is required to have high compressive strength, low absorption and should exhibit high bond strength. Most published values for wet mix shotcrete have compressive strengths greater than 30 MPa. In the current application, as a surface sealant for ARD control, high strength shotcrete is not essential as long as it remains crack free and prevents water and oxygen from reaching the waste rock. In addition, the shotcrete cover is not required to support a load. The relationship between strength and durability as demonstrated in normal concrete mixes recommends that a minimum compressive strength be part of the design requirements for a well-proportioned concrete mixture. The compressive strength design objective in this study was in the order of 15 to 20 MPa. A critical aspect of a high strength shotcrete mix is a proper gradation of aggregates. The use of mine tailings in the cementitious

mixtures does not satisfy the gradation requirements as specified by ASTM. Nonetheless, the mixtures achieved strength gains in the order of the designed objectives.

The approach used in this study to minimize the formation of shrinkage cracks in shotcrete was the incorporation of polypropylene fibers and fly ash. Although cementitious mixtures containing high volume fly ash require longer curing times to reach full strength, the compressive strengths attained within a 7 day period can be as high as 12 MPa. Figures 11 and 12 show the compressive strengths of the lab mixes and the shotcrete panels as a function of the curing time. The results illustrate that, in general, there was considerable strength gain in the mixes between 28 and 91 days of curing. The highest strength obtained in the shotcrete panels after 91 days was 26.9 MPa in mix B1.

Figures 13 and 14 show the effect of tailings content on compressive strength in the lab mixtures and in the shotcrete panels. For samples with comparable tailings contents, the lab mixtures achieved higher strengths than the shotcrete panel samples with the greatest differences noted in the samples with the highest tailings contents. Differences in consolidation methods between field and laboratory samples may account for the observed differences in strengths. The laboratory mixtures were consolidated with the use of a vibratory table while the test panel samples relied on the velocity of the impact during the shotcrete process for consolidation. The fine grain size characteristic of the tailings (in the silt to fine sand range) combined with the lack of a well graded aggregate component may also have influenced the consolidation of the cementitious samples.

The total cementitious content in the majority of the mixtures was kept constant at 25% of the total mixture by weight. Figure 15 shows the effect of cementitious content on compressive strength. The results indicate that the mixture with the lowest cementitious content (laboratory mixture C) showed lower strengths at all stages of

curing. In addition, the mixture with the lowest cementitious content experienced bleeding during consolidation indicating a requirement for a larger quantity of cementitious material.

The effect of the cement to fly ash ratio on compressive strength of the cementitious mixtures was also evaluated. Figure 16 and 17 show that a higher cement to fly ash ratio resulted in higher strength gain even at 91 days of curing. However, this effect may be offset by a longer curing period.

5.2 Flexural Properties

Concrete is a brittle material with a very low tensile strength. Unreinforced concrete will tend to crack and separate following a small deflection. However, the shotcrete material developed in this study is to be used as a surface sealant on a waste rock dump; therefore, the hardened concrete will require ductility to withstand local settlement within the rock slope. In most shotcrete designs the desired toughness indices are usually $I_5 > 3$ and $I_{10} > 6$ (see Figure 3 for a definition of these terms). The shotcrete mixtures were therefore designed to match or exceed these indices. The flexural properties of all the mixtures in both the lab trials and the shotcrete panels showed good ductility. Tables 4, 7 and 8 showed that the majority of samples tested had toughness indices exceeding the desired values. Lab mixture E, which contained the highest cement content together with 100% mine tailings as aggregate, had toughness indices lower than the design values. It is uncertain whether the lower toughness index for this sample was due to the higher cement content or the large quantity of fine-grained aggregate in the sample. The addition of polypropylene fibers in the mixtures appears to restrict the propagation of cracks by improving the tensile strength of the composite material.

5.3 Permeability

A correlation between absorption and permeability as an index of shotcrete quality in terms of strength has been reported⁶. Because of the fine-grained nature of the mine

tailings used as aggregate in the study, both the absorption and the volume of permeable voids was high indicating that the shotcrete produced would be considered to be of marginal quality. Testing showed that as the quantity of sand and gravel in the cementitious mixtures was increased the absorption and volume of permeable voids decreased. Permeability testing, however, indicated that all mixtures had low permeabilities to water in the order of 10^{-10} m/s. Air void examination of the hardened cementitious mixtures showed air contents of less than 5%, suggesting that the elevated absorption values are due to the high surface area of the fine-grained mine tailings and do not represent void spaces which would contribute to increased permeability of the sample. In addition, microscopic examination of the cementitious structure showed a well distributed air void system without interconnecting pores, entrapped air and micro-cracks. During field spraying of the shotcrete mixtures it was found that an overdose of air entrainment additive was required to achieve the desired air void content following shotcreting. It is unclear, at this time, how the high absorption values measured will affect the long-term durability of the cementitious mixtures.

5.4 Durability

Although freeze-thaw resistance was not evaluated in this study, air void examination showed that the shotcrete mixtures developed may have good freeze-thaw resistance because of the air contents measured and the shape of the air voids.

Analysis of mine tailings used as aggregate in this study indicated abnormally high sulfate content in the order of 1.5%. The Portland Cement Association recommends a maximum permissible sulfate content of 0.5% to avoid sulfate attack of the concrete structure. Subsequent discussions with Westmin Mines personnel indicated that tailings with a more suitable sulfate content is available at the mine site in sufficient quantities. The use of sulfate resistant cement may also alleviate concerns regarding long term durability of the cementitious mixtures.

6.0 COST

The chief advantage of using the shotcrete mixes developed in this study is that the aggregate content may be obtained from the site, thereby avoiding the high cost of transporting aggregate from Campbell River.

The material costs for this study are:

1. Flyash - transported to Westmin	\$ 90./metric tonne
2. Type 10 cement - transported to Westmin	\$140./metric tonne
3. Polypropylene fibres (.9kg/bag)	\$ 6.50/bag
4. Air entrainment agent	\$ 1.90/litre
5. Superplasticizer	\$ 3.19/litre

The total materials costs assuming the aggregate can be obtained from the site without cost are:

Material	Quantity/m ³	Cost/m ³	Cost/m ²
fly ash	288 kg	\$25.92	\$2.59
cement	192 kg	\$26.88	\$2.69
fibres	5 kg	\$36.11	\$3.61
air entrainment	0.9 litre	\$ 1.82	\$0.18
superplactizer	2.16 litre	\$ 6.89	\$0.69

The total material cost for a cubic metre of shotcrete is \$97. Assuming that the average thickness of the shotcrete is 100 mm, the total material cost for a square metre of shotcrete is \$9.70.

The cost for application of the shotcrete onto the rock slope will depend on several factors including the condition of the rock slope, and the type of equipment used. Manual application, with an operator suspended from the top of a rock slope will result in the lowest production rate. The application rate will increase if the operator is shooting from an aerial lift device. Terracrete Systems is now developing a robotic shotcrete unit which may further increase the application rate.

7.0 CONCLUSIONS AND RECOMMENDATIONS

A study was conducted to develop a shotcrete mixture incorporating mine tailings which can be used as a surface sealant on sloping waste rock surfaces to control acid rock drainage. Five cementitious mixes were prepared and tested in the laboratory to optimize the use of polypropylene fibers, fly ash and mine tailings. Based on testing of the laboratory mixtures, proportions of materials were modified for the shotcrete test panels. The panels were shot and tested in accordance to established ASTM and CSA procedures. The field results showed that the mixtures can be placed onto vertical surfaces using the wet-mix shotcrete method. Testing indicated that:

- The mine tailings could be effectively incorporated into a cementitious mixture and the mixtures were easily workable, even with the low water to cement ratio used in this study.
- Mixtures with a high volume of fly ash attained 91 day strengths as high as 26 MPa.
- The minimum cementitious material content required to produce mixtures with acceptable physical properties was determined to be 25% of the total weight of the mixture.

- The laboratory mixtures show that up to 100% mine tailings, as aggregate, can be incorporated into the mixture without adversely affecting the compressive strength of the solidified mixtures. However, testing of the shotcrete panels indicated that quantities of mine tailings in excess of 40%, as aggregate, will adversely affect the compressive strength of the solidified cementitious mixture.
- An overdose of air entrainment additive was required to achieve the desired air void content following shotcreting.
- Water permeability of all the shotcrete mixtures was very low in the order of 10^{-10} m/s.
- The addition of polypropylene fibers contributed to ductility of the solidified materials.
- The toughness indices indicate that the solidified cementitious materials will likely resist major cracking as a result of local settlement in an environment such as a waste rock dump.

Further work is recommended to enable field testing of shotcreted cementitious mixtures for use as a surface sealant to restrict acid generation. The use of covers (either layered, synthetic or solidified) to restrict acid generation and control acid rock drainage has not been fully evaluated under field conditions. This study has shown that a fiber reinforced solidified cementitious cover can be applied using shotcreting methods to sloping waste rock surfaces. It is therefore recommended that this material be used as a surface sealant in a pilot scale model to evaluate the effectiveness of the cover to restrict acid generation within a waste rock pile. The pilot scale system would be modelled after the waste rock dump conditions at Westmin's Myra Falls operations. Such a testing system would evaluate material properties such as durability and weatherability as well as leachability of the solidified cover. In

addition, acid mine drainage parameters would be monitored to determine the effectiveness of the cover in restricting acid generation within the waste rock pile. It is important to initiate pilot scale testing as soon as possible to ensure data collection over a suitably long period of time.

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TABLES

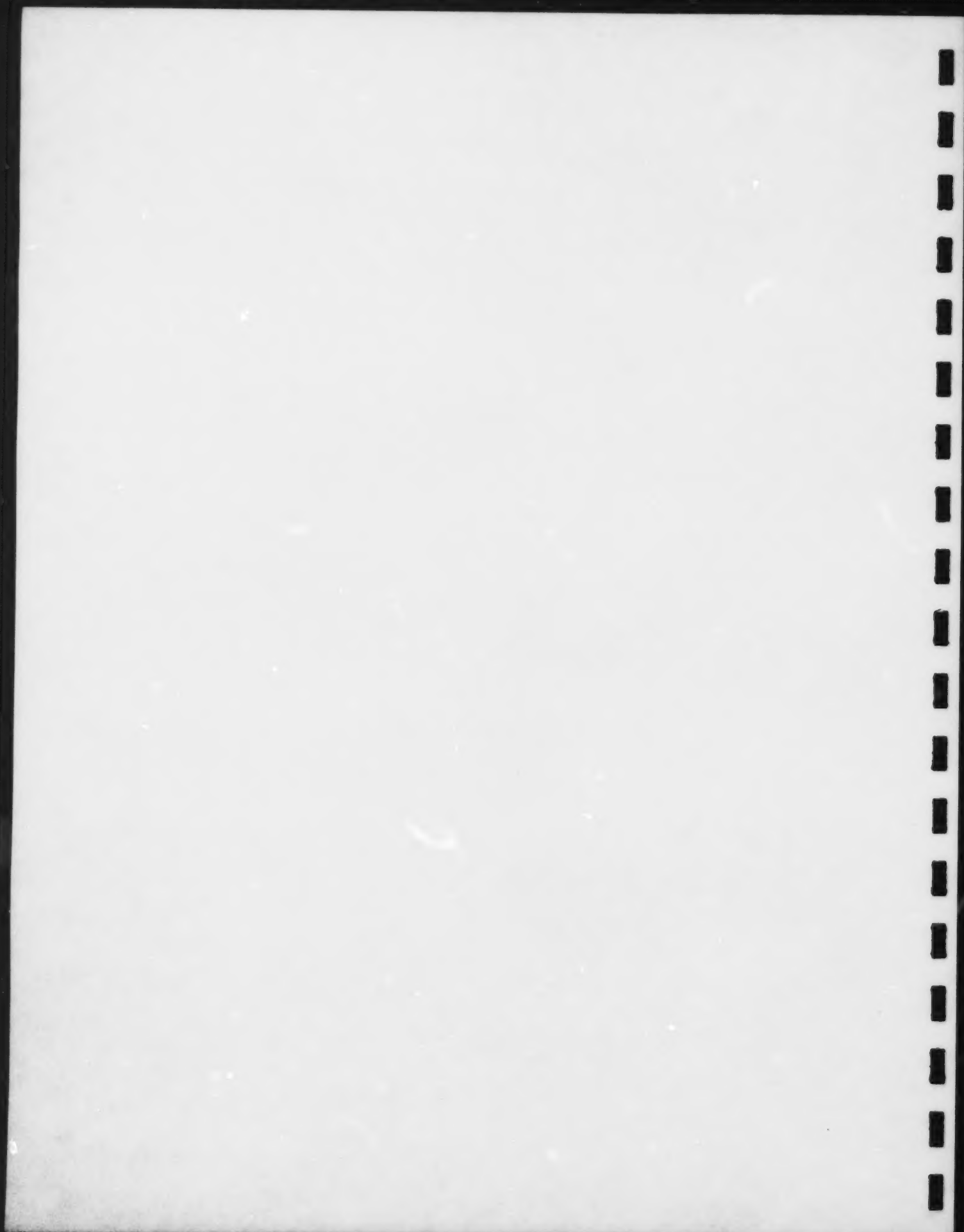


Table 1: Mix proportions of the laboratory trial mixes

MIX	TAILINGS kg/m ³	CEMENT kg/m ³	FLY ASH kg/m ³	GRAVEL kg/m ³	SAND kg/m ³
A	1152	192	288	58	230
B	576	192	288	130	410
C	1152	140	210	58	230
D	1440	192	288	0	0
E	1440	240	240	0	0

* Dosage of polypropylene fibres was 5 kg / m³ for all mixes

Table 2: Properties of fresh concrete

MIX	AIR CONTENT (%)		SLUMP (mm)	
	without fibres	with fibres	without fibres	with fibres
A	4.5	7	89	64
B	7	12	152	83
C	4.8	4.0	51	25
D	3.8	3.5	76	51
E	4.5	4.3	44	32

Table 3: Compressive strength of laboratory trial mixes

MIX NO.	COMPRESSIVE STRENGTH (MPa)		
	7 Days	28 Days	91 Days
A	7.1	10.5	14.6
	7.3	9.9	14.1
	7.5	10.8	-
B	9.6	10.9	15.6
	9.8	10.6	15.6
	9.7	-	15.1
C	5.8	7.5	10.9
	5.8	7.5	10.9
	6.0	7.7	11.3
D	6.3	10.8	13.1
	6.4	9.7	15.1
	7.0	10.3	15.1
E	10.1	14.2	14.6
	10.5	14.7	21.2
	10.2	14.6	21.7

Table 4: Toughness tests of laboratory trial mixes - 28-day moist cure

MIX	A	B	C	D	E
Peak Load (N)	10675	5071	3558	6628	6805
Flexural Strength (kPa)	1854	1448	1034	1923	1993
Deflection at First Crack (mm)	.406	.533	.610	.305	.356
Deflection at 3 Times First Crack (mm)	1.22	1.60	1.83	0.91	1.07
Deflection at 5.5 Times First Crack (mm)	2.24	2.93	3.35	1.68	1.96
Toughness Index I_5	3.8	3.6	4.0	3.5	2.5
Toughness Index I_{10}	8.1	8.1	9.1	7.8	4.8

* Sample dimensions for this sample were 125 x 125 x 350 mm

Table 5: Mix proportions of shotcrete mixes

MIX	TAILING kg/m ³	CEMENT kg/m ³	FLY ASH kg/m ³	GRAVEL kg/m ³	SAND kg/m ³
A1	1152	192	288	58	230
B1	576	192	288	173	691
C1	576	240	240	173	691
D1	1440	192	288	0	0
E1	1440	240	240	0	0

Table 6: Compressive strength of shotcrete mixes

MIX NO.	COMPRESSIVE STRENGTH (MPa)		
	7 Days	28 Days	91 Days
A1	2.7	4.6	7.4
	2.6	4.4	8.2
B1	12.2	15.1	26.6
	13.3	14.6	26.9
C1	7.6	13.2	17.4
	7.4	13.7	18.4
D1	2.3	8.9	8.4
	2.5	8.9	7.9
E1	5.6	10.1	13.1
	5.1	8.8	13.1

Table 7: Toughness tests of shotcrete panels - 7-day moist cure

MIX	A1	B1	C1	D1	E1
Peak Load (N)	2891	6182	4982	3336	4270
Flexural Strength (mm)	724	1800	1400	883	1262
Deflection at First Crack (mm)	.483	.343	.305	.305	.330
Deflection at 3 Times First Crack (mm)	1.45	1.035	0.91	0.91	0.99
Deflection at 5.5 Times First Crack (mm)	2.65	1.89	1.68	1.68	1.82
Toughness Index I_5	4.9	3.3	4.2	5.3	3.6
Toughness Index I_{10}	10.8	6.9	9.1	11.3	7.2

Table 8: Toughness tests of shotcrete panels - 28-day moist cure

MIX	A1	B1	C1	D1	E1
Peak Load (N)	5115	5293	7739	6316	6227
Flexural Strength (kPa)	1627	1551	2234	1862	1813
Deflection at First Crack (mm)	0.99	0.229	0.584	0.356	0.318
Deflection at 3 Times First Crack (mm)	2.97	0.69	1.75	1.07	0.95
Deflection at 5.5 Times First Crack (mm)	5.45	1.26	3.21	1.96	1.75
Toughness Index I_5	5.0	4.1	4.2	3.7	3.1
Toughness Index I_{10}	8.5	8.2	8.4	8.0	6.3

Table 9: Air void content of hardened shotcrete panels

MIX	AIR VOID CONTENT (%)
A1	1.56
B1	3.45
C1	3.05
D1	1.71
E1	2.80

C642-90 SPECIFIC GRAVITY
ABSORPTION & VOIDS IN HARDENED CONCRETE0602-8080/98/0000-0000\$05.00/0

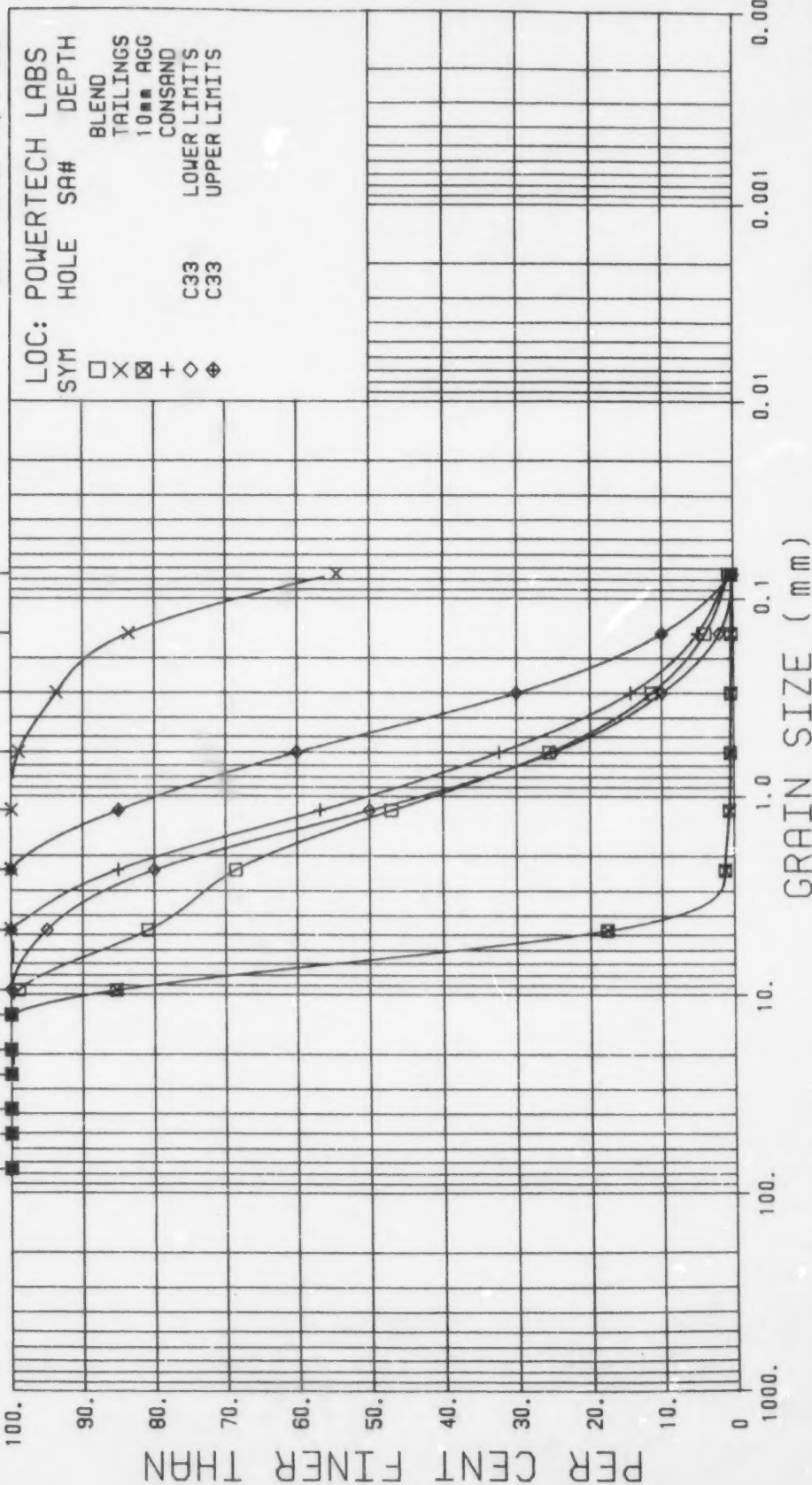
Table 11. Permeability of shotcrete panels

MIX	PERMEABILITY (m/s)
A1	6.12×10^{-10}
B1	5.88×10^{-11}
C1	1.46×10^{-12}
D1	1.69×10^{-11}
E1	3.58×10^{-11}

FIGURES



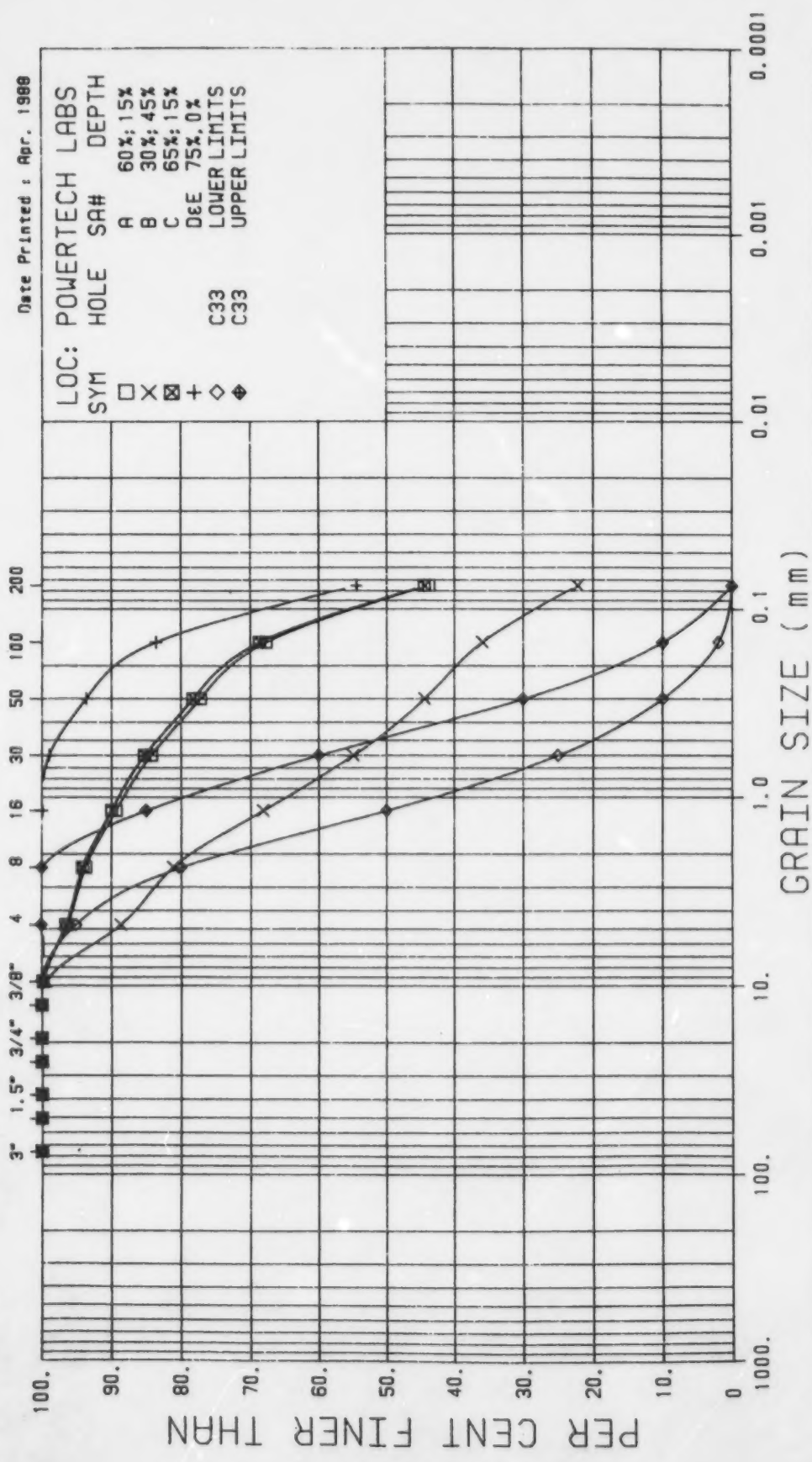
Date Printed : Apr. 1988



BOULDER SIZE	COBBLE SIZE	GRAVEL SIZE			SAND SIZE		FINE GRAINED		CLAY SIZE
		COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	

Figure 1: Gradation of aggregate

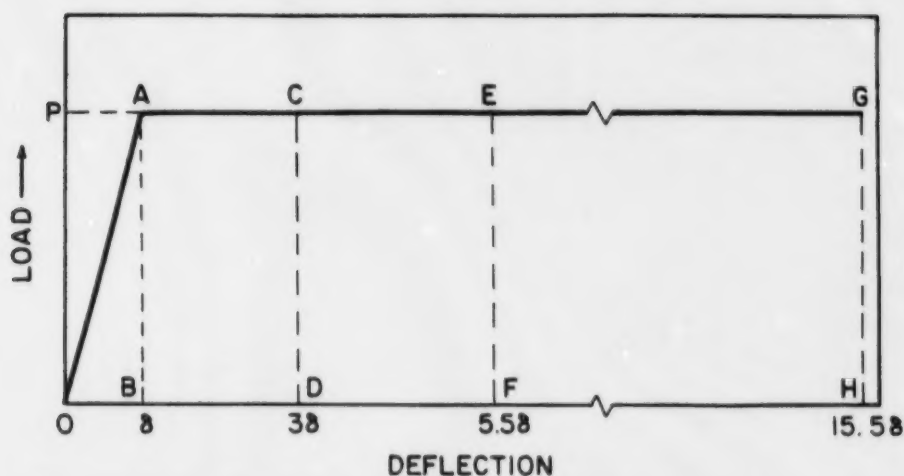
Date Printed : Apr. 1988



BOULDER SIZE	COBBLE SIZE	GRAVEL SIZE			SAND SIZE		SILT SIZE		FINE GRAINED	
		COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE	

Figure 2: Gradation of lab mixes

C 1018



Area Basis ^A	Index Designation	Deflection Criterion	Values of Toughness Indices		
			Plain Concrete	Elastic-Plastic Material	Observed Range for Fibrous Concrete
OACD	I_8	38	1.0	5.0	1 to 6
OAEF	I_{10}	5.58	1.0	10.0	1 to 12
OAGH	I_{30}	15.58 ^B	1.0	30.0	1 to 40

^A Indices calculated by dividing this area by the area to the first crack OAB.

^B Corresponds approximately to the 1.9-mm (0.075-in.) criterion for 300 by 100 by 100-mm (12 by 4 by 4-in.) specimens tested under third-point loading.

Figure 3: Schematic of toughness test

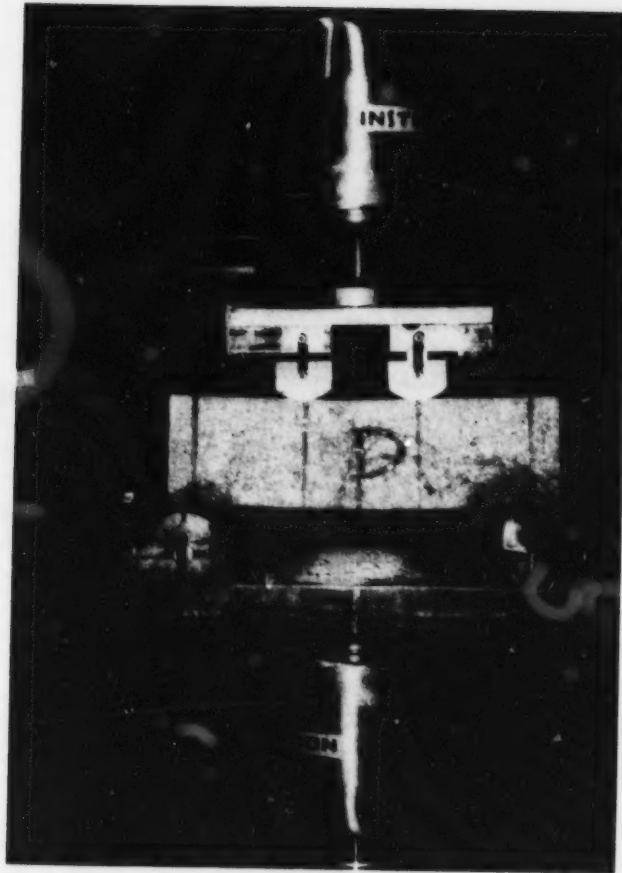


Figure 4: Flexural test - note the beam is still intact after the crack has initiated.

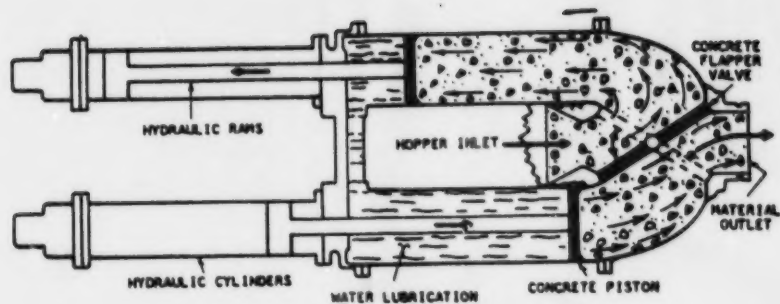


Figure 5: Schematic of pumping equipment

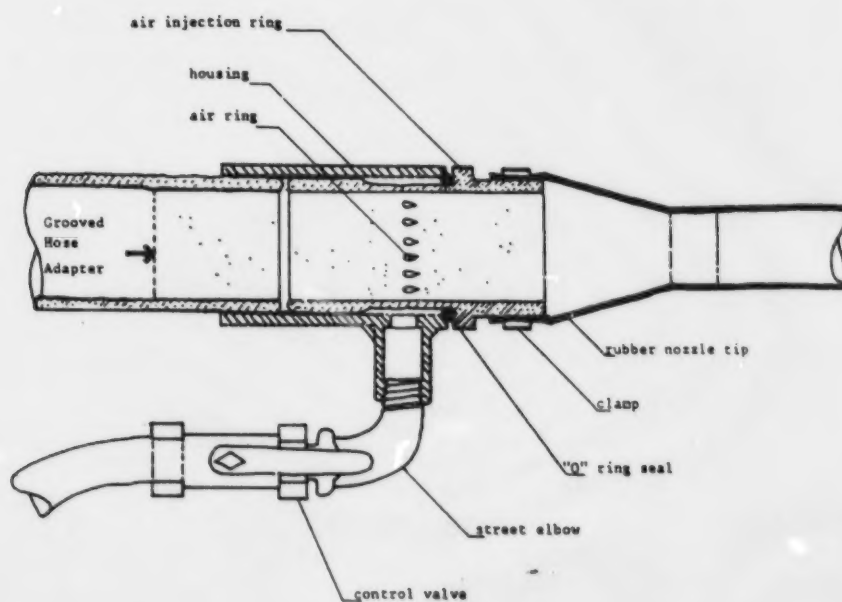


Figure 6: Schematic of a wet mix nozzle



Figure 7: Shotcrete pump

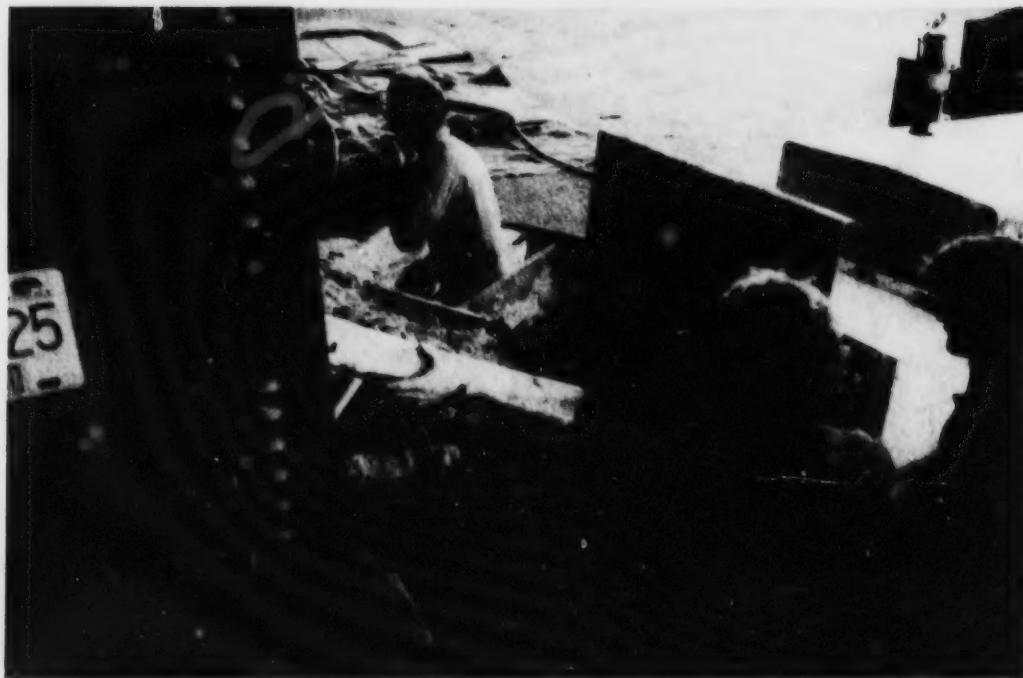


Figure 8: Mixture is transferred from the mixer to the pump hopper.

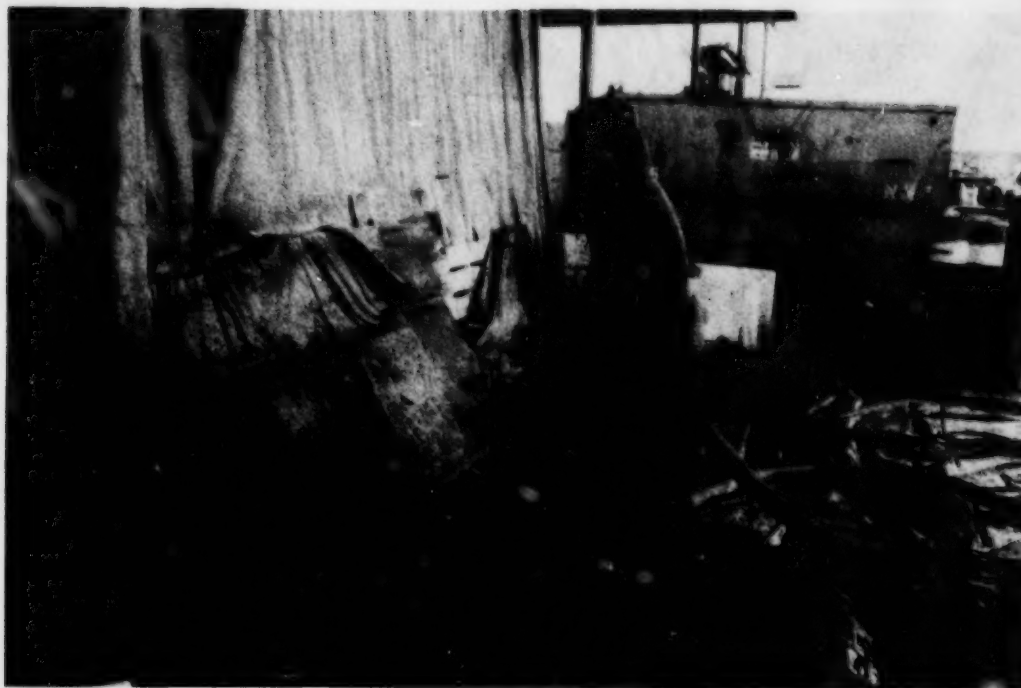


Figure 9: Shotcrete of test panels

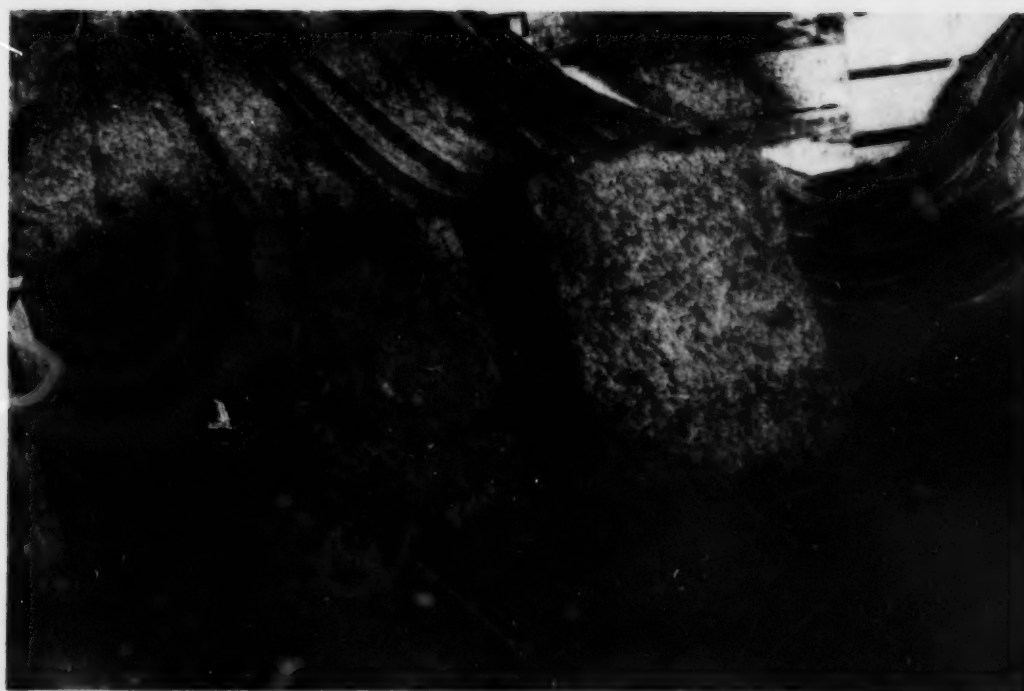


Figure 10: Test panels after shooting

FIGURE 11. COMPRESSIVE STRENGTH OF LAB MIXES

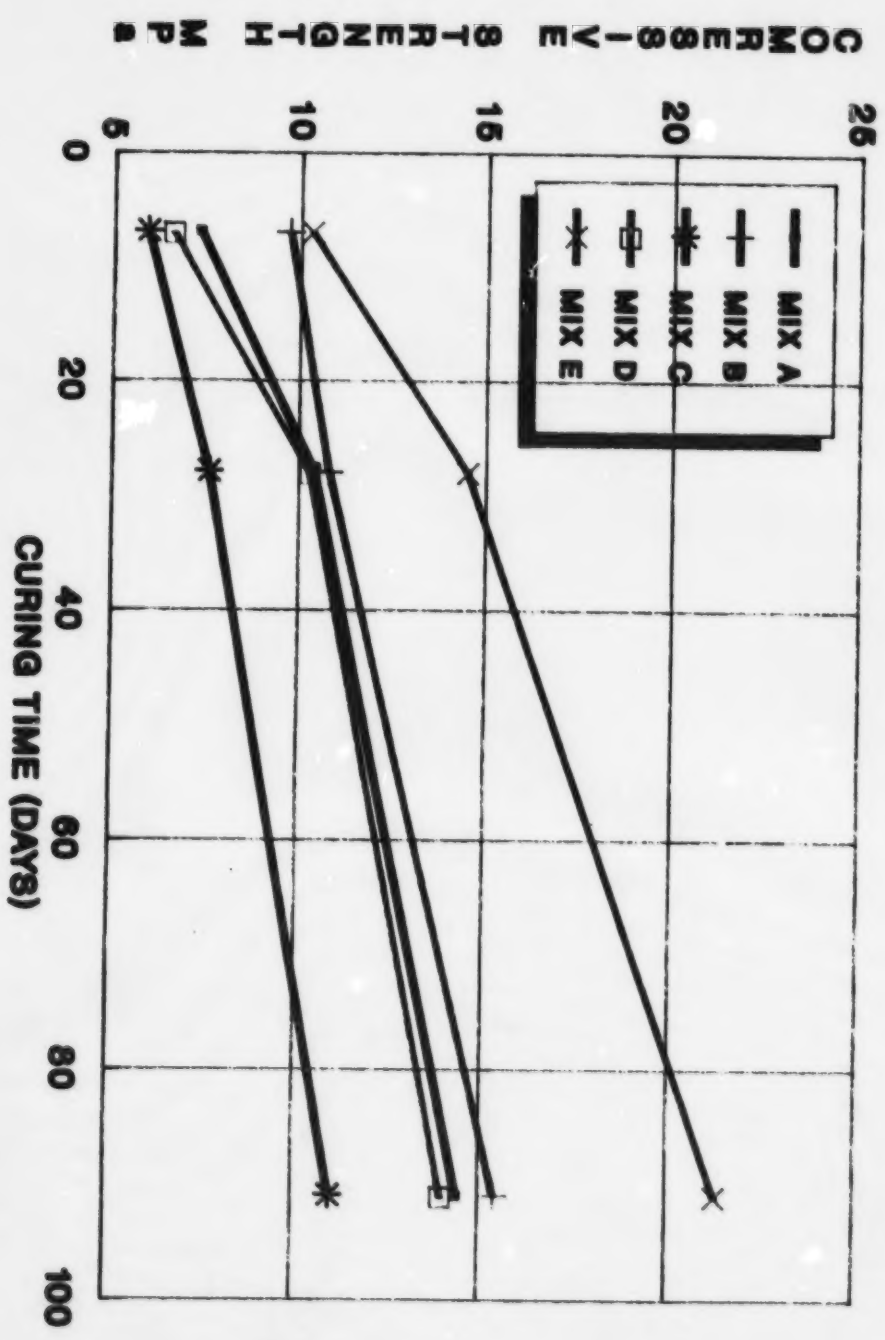


FIGURE 12. COMPRESSIVE STRENGTH
OF SHOTCRETE PANELS

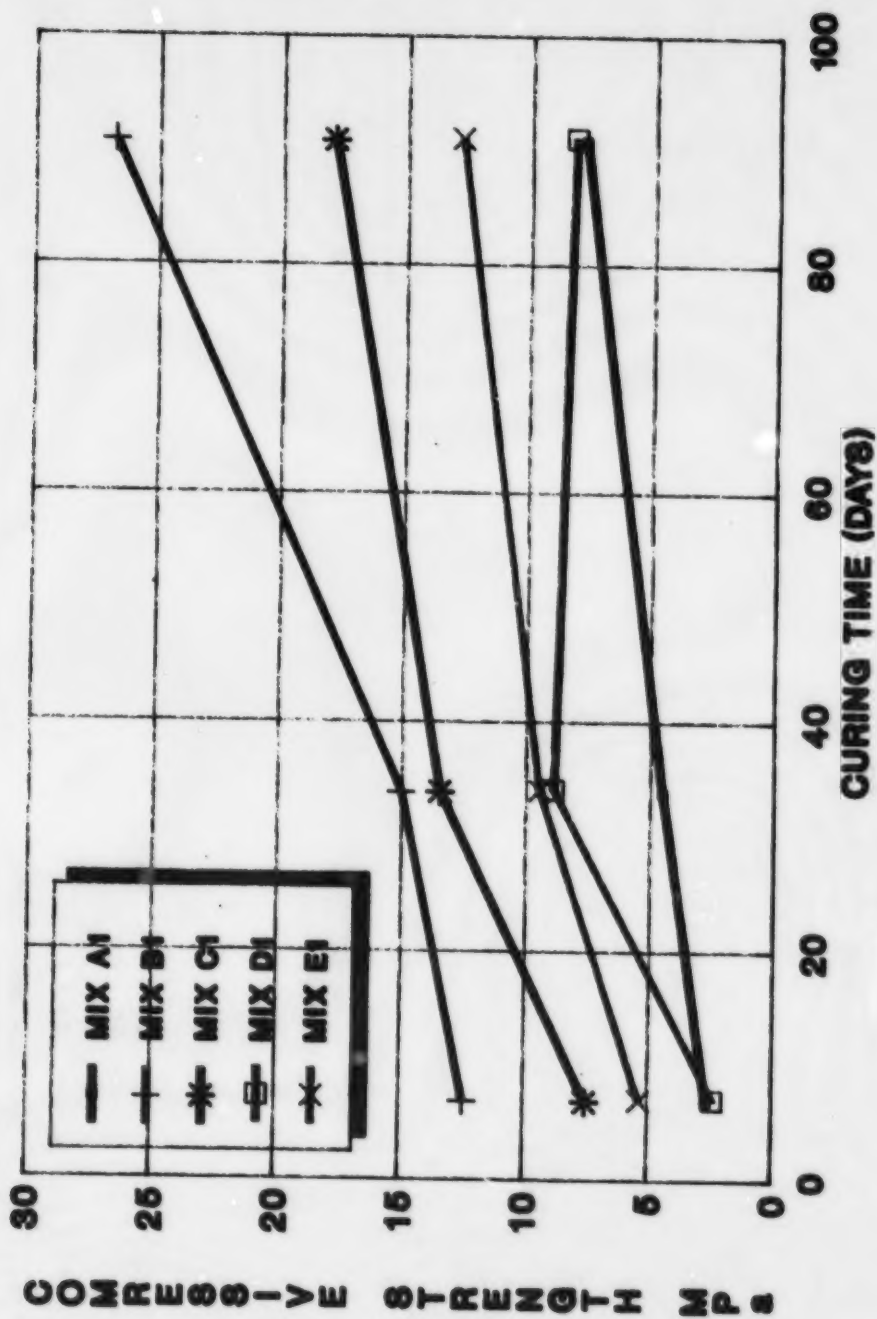


FIGURE 13. EFFECT OF TAILINGS CONTENT
COMPRESSIVE STRENGTH

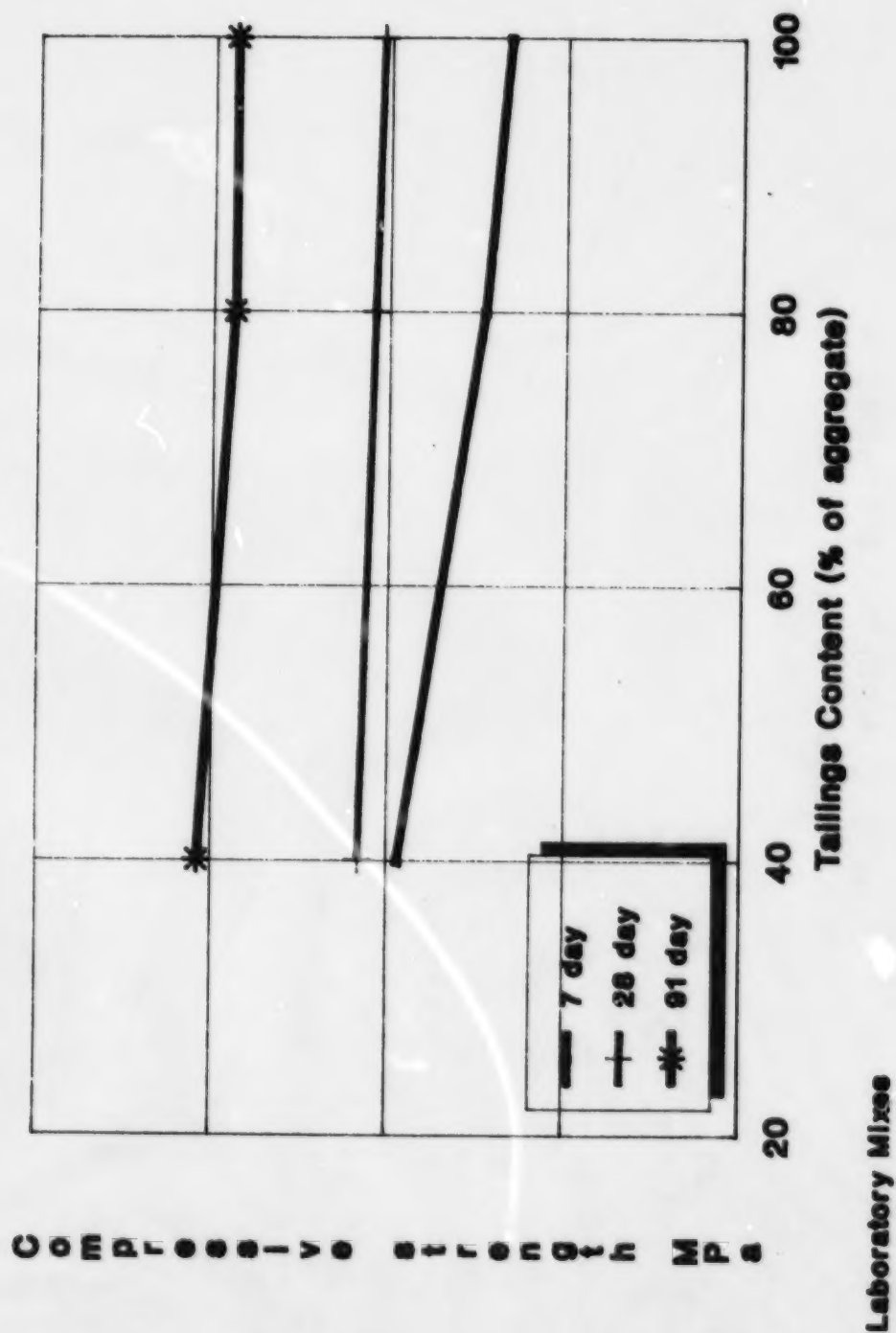


FIGURE 14. EFFECT OF TAILINGS CONTENT
ON COMPRESSIVE STRENGTH

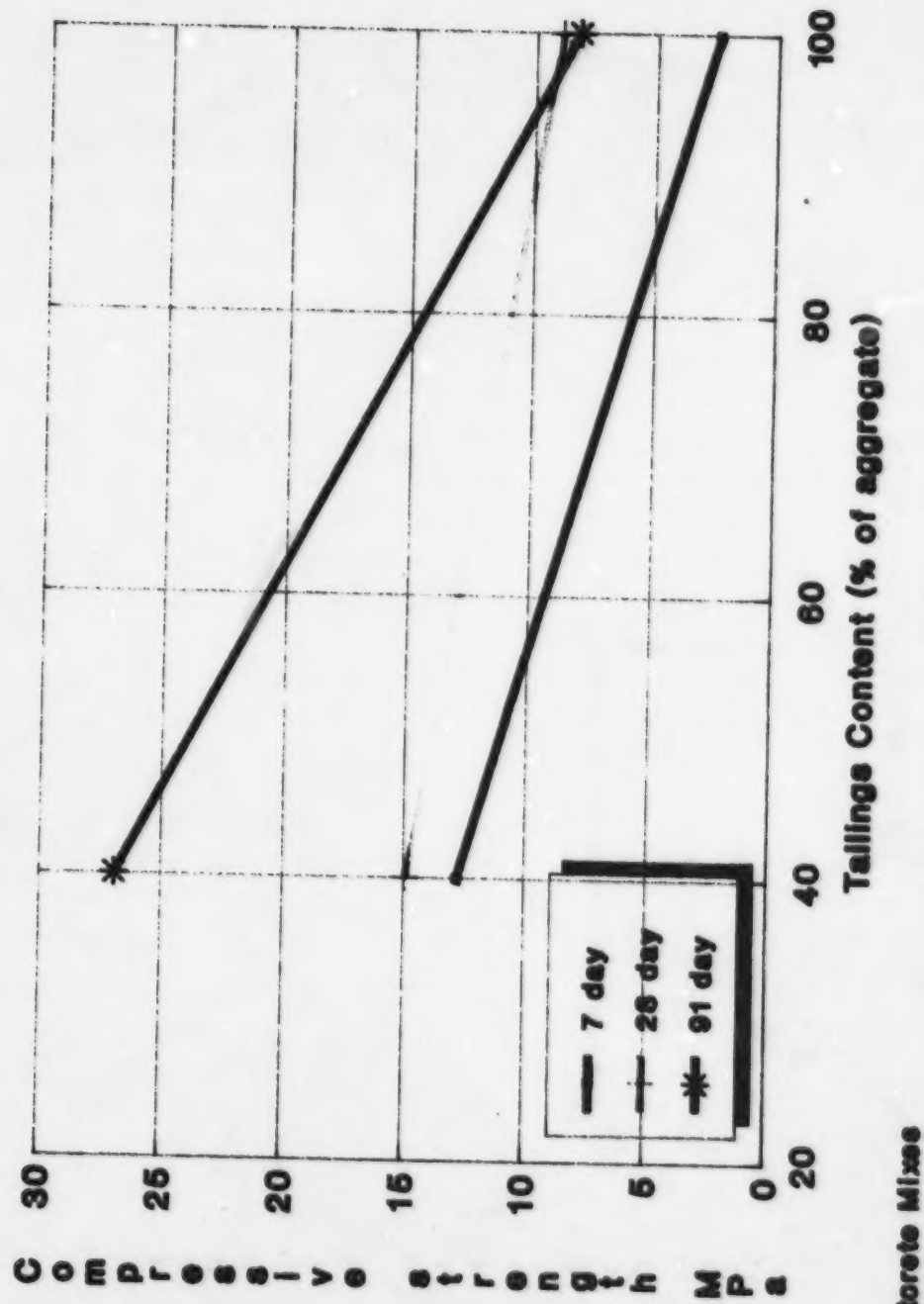
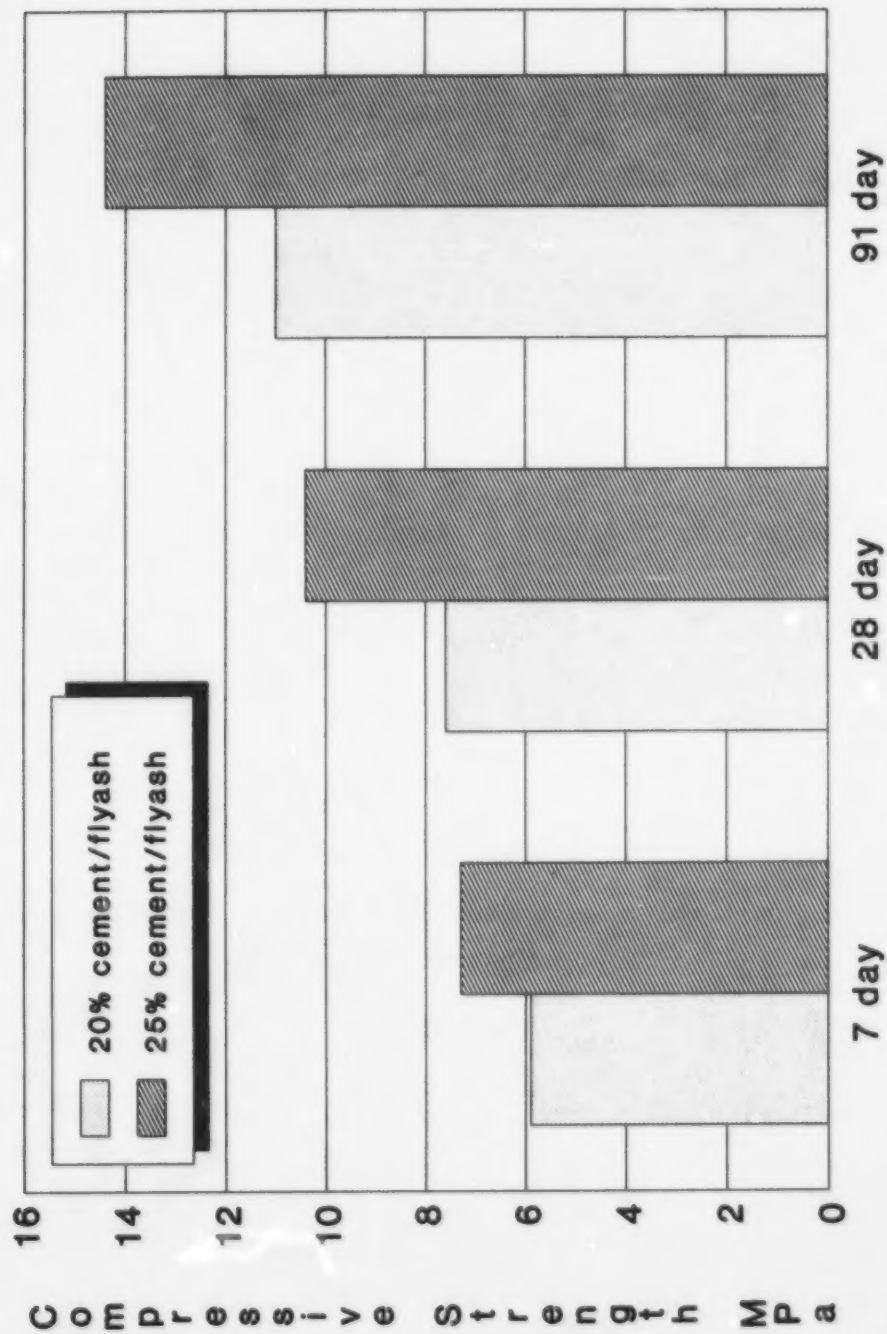
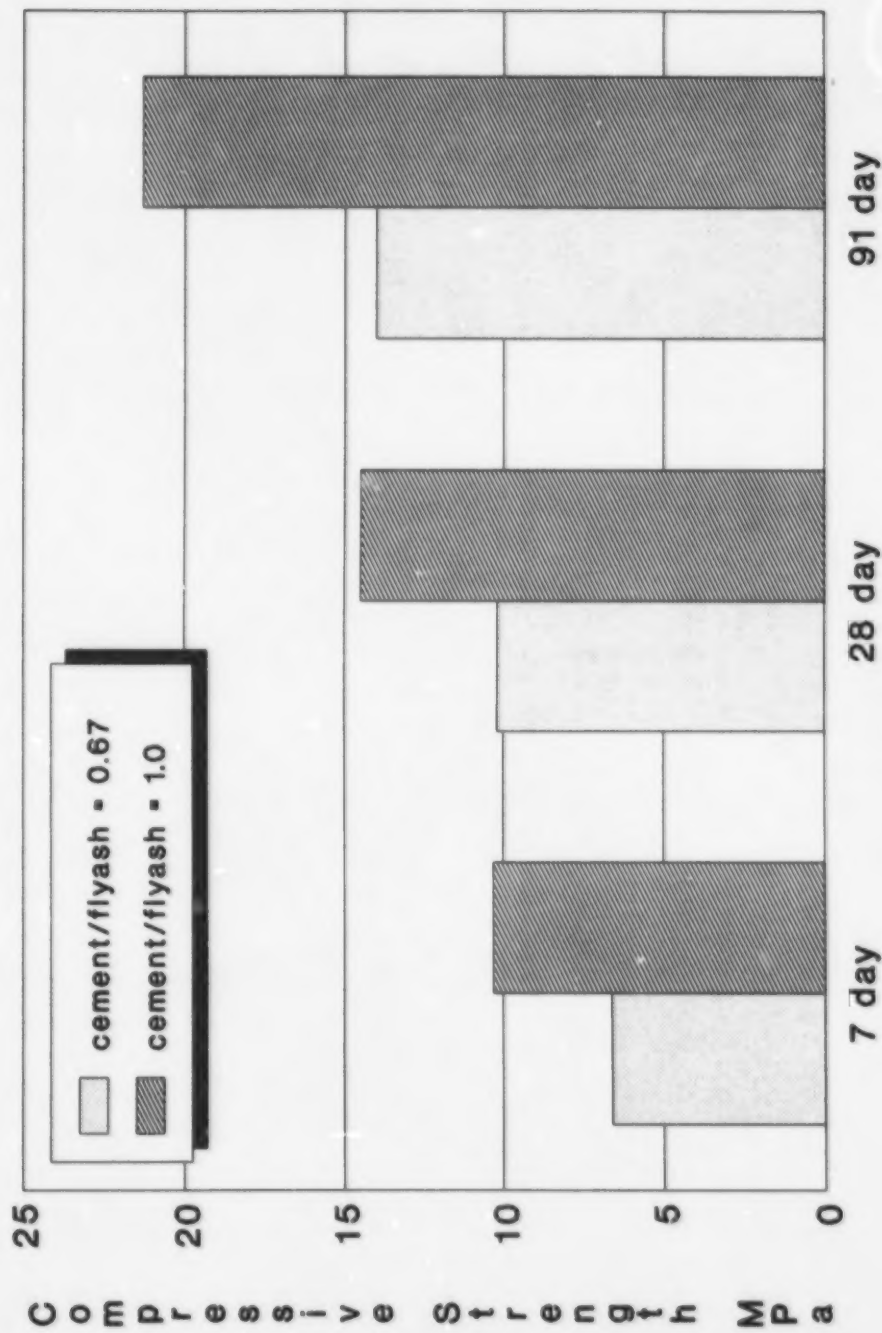


FIGURE 15. EFFECT OF CEMENTIOUS CONTENT
ON COMPRESSIVE STRENGTH



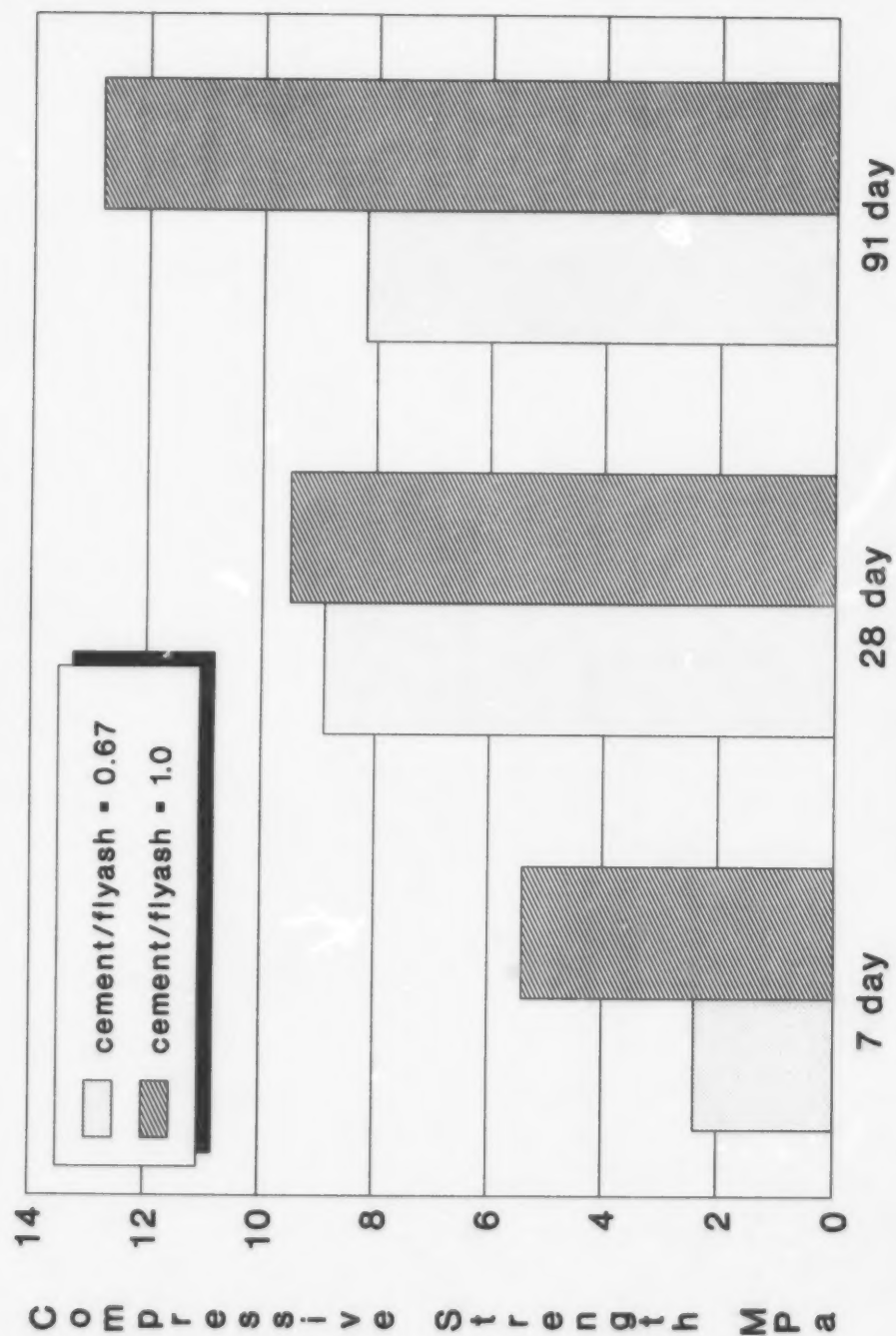
Laboratory Mixes

**FIGURE 16. EFFECT OF CEMENT CONTENT
ON COMPRESSIVE STRENGTH**



Laboratory Mixes • 100% tailing

FIGURE 17. EFFECT OF CEMENT CONTENT
ON COMPRESSIVE STRENGTH

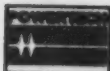


Shotcrete Panels @ 100% tailing

APPENDICES

APPENDIX A

MATERIAL CHARACTERIZATION



PowerTech Labs Inc.
12388 - 88th Ave
Surrey, B.C. V3W 7K7

SPECIFIC GRAVITY & ABSORPTION OF COARSE AGGREGATE (ASTM C127)

MATERIAL TYPE: 10mm Aggregate

- | | | |
|----|--|---------------|
| 1) | wt. of sample (B)
(saturated-surface-dry) | <u>1138 g</u> |
| 2) | wt. of sample (C)
(sat. surface dry in water) | <u>724 g</u> |
| 3) | wt. of sample (A)
(dry) | <u>1117 g</u> |

BULK SPECIFIC GRAVITY:

$$\text{bulk s.g.} = \frac{A}{(B-C)} = 2.69$$

BULK SPECIFIC GRAVITY (SATURATED-SURFACE-DRY)

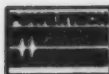
$$\text{bulk s.g.} = \frac{B}{(B-C)} = 2.75$$

APPARENT SPECIFIC GRAVITY

$$\text{App. s.g.} = \frac{A}{(A-C)} = 2.84$$

ABSORPTION %

$$\text{Absorption} = \left[\frac{(B-A)}{A} \right] \times 100 = 1.89\%$$



Conc. Sand (H)

**SPECIFIC GRAVITY & ABSORPTION OF
FINE AGGREGATES
ASTM (C128)**

amt. of water used	_____ ml
wt. of pycnometer #B	_____ 163.25 g
wt. pf pycnometer & water (B)	_____ 661.75 g (21°C)
wt. of dried sample (A)	_____ 106.72 g

Total weight of pycnometer, water & sample (C):

$$C = 0.9976 V_s + 500 + W$$

V_s = Vol. of H₂O added

W = wt of pycnometer

$$C = 732.07$$

Bulk Specific Gravity

$$Sp\ Gravity_s = \frac{A}{(B + 110.29 - C)} = 2.67$$

Bulk Specific Gravity (S.S.D.)

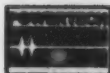
$$Sp\ Gravity_{(S.S.D.)} = 110. \frac{29}{(B + 110.29 - C)} = 2.76$$

Apparent Specific Gravity

$$Sp\ Gravity_{(app.)} = \frac{A}{(B + A - C)} = 2.93$$

Absorption %

$$Absorption = \left[\frac{(110.29 - A)}{A} \right] \times 100 = 3.35\%$$



Powertech Labs Inc
12000 - 88th Ave
Surrey, B.C. V3W 7K7

SPECIFIC GRAVITY OF SOILS (ASTM D854)

WESTMIN COARSE TAILINGS

wt. of volumetric flask	(F) (A)	<u>157.13</u>	
wt. of volumetric flask & water	(20 °C)	<u>655.56</u>	(W _a)
wt. of flask, water & sample	(20 °C)	<u>733.22</u>	(W _b)

wt. of tare & dried sample	<u> </u>
wt. of tare	<u> </u>
wt. of dry sample (W _o)	<u>108.01</u>

$$\text{Specific Gravity}_{(20^\circ)} = \frac{K(W_o)}{W_o + (W_a - W_b)}$$
$$= 3.55$$

SP-GD854.1

COMMERCIAL TESTING LABORATORIES
A DIVISION OF CTL/THOMPSON, INC
11 LIPAN STREET DENVER, COLORADO 80221 303-825-3107

CHEMICAL AND PHYSICAL ANALYSES OF FLY ASH

TICKET NUMBER: 2154- 32990 Job Number: 2154 REPORT DATE: 01/15/91

REPORT TO: Pozzolanic Northwest
7525 SE 24th Street
Suite 630
Mercer Island , WA 98040

PLANT OF ORIGIN : Centralia
SAMPLE ID : #085-90
DOCKETS : 5061-5116
DATE SAMPLED : - - - -
DATE RECEIVED : 11/14/90

CAN/CSA-A23.5-M86(1987)
SPECIFICATIONS

CHEMICAL COMPOSITION(%):

TYPE F

Silicon Dioxide	47.77	
Aluminum Oxide	24.97	
Iron Oxide	6.98	
" " " Total	79.72	
Sulfur Trioxide	0.36	5.0 Max
Calcium Oxide	8.18	
Moisture Content	0.06	3.0 Max
Loss on Ignition	0.02	12.0 Max

PHYSICAL TEST RESULTS:

Fineness		
Retained on 45 um sieve, (%)	20.62	34 Max
Pozzolanic Activity Index		
With Portland Cement (%)		
Accelerated (7 days @ 65 C)	90.8	68 Min
ASTM C-311 (28 days @ 38 C)	- -	75 Min
With Lime @ 7 days (MPa)	7.03	
Water Requirement, % of Control	93.0	
Soundness		
Autoclave Expansion (%)	-0.039	0.8 Max
Density (g/cc)	2.31	
Increase of Drying Shrinkage (%)	- -	0.03 Max

Comments: - -

COMMERCIAL TESTING LABORATORY

By

Orville R. Werner II, P.E.



22 October 1990

To: C. Gung

From: G. Ashby

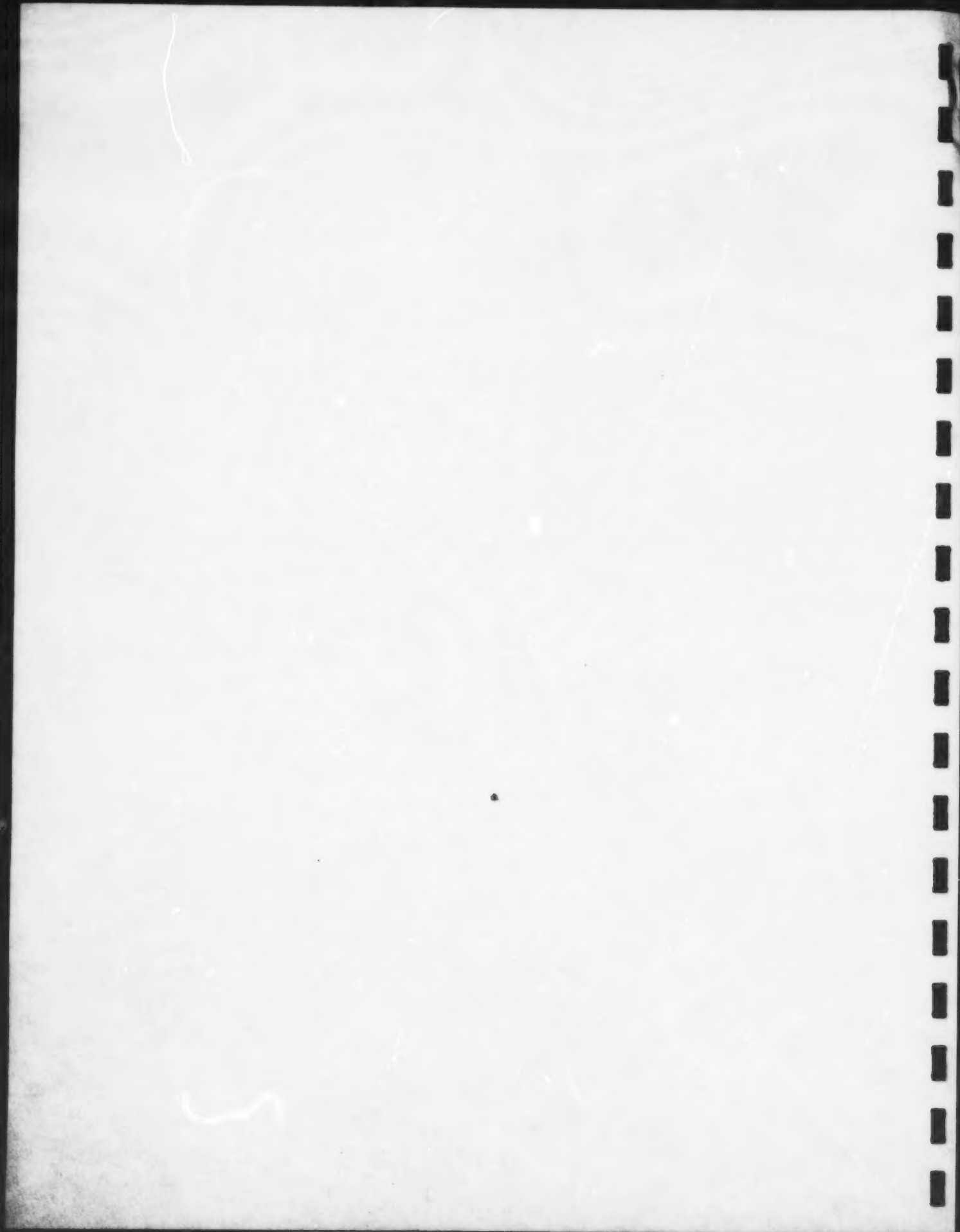
Subject: PROJECT:2418-34 Sulphate determination in silt and sludge samples.

The samples were dried at 105°C then extracted three times by boiling with water. The water extracts were treated with sodium carbonate to precipitate heavy metals, filtered, and acidified. Sulphate was precipitate using barium chloride and determined gravimetrically.

Sulphate (%)

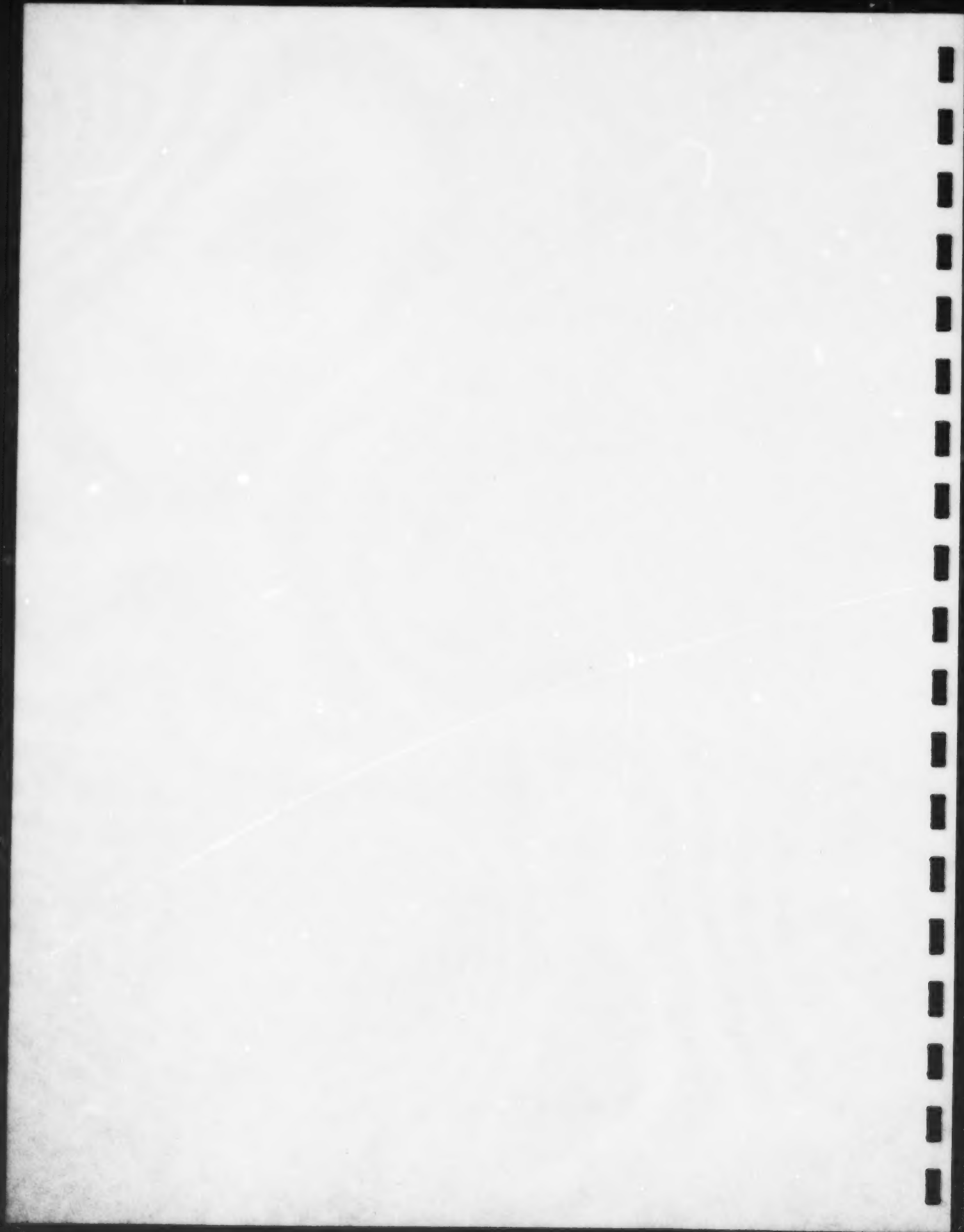
Silt	1.10
Sludge	1.54

G. Ashby



APPENDIX B

COMPRESSIVE STRENGTH TESTS





CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Lab Mix A	
Client:		Date Cast: 90-11-01	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: A	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
A3	7	90-11-7	100	63	7.3
A4	7	90-11-7	100	61.5	7.1
A5	7	90-11-7	100	65.25	7.5
A6	28	90-11-28	100	85.5	9.9
A7	28	90-11-28	100	93.75	10.8
A8	28	90-11-28	100	90.75	10.5
A9	89	91-01-30	100	126	14.6
A10	28	90-11-28	100	90.75	10.5
A11	89	91-01-30	100	122.3	14.1

Distribution of Report:

TSS
TESTED BY:

J.Y. Wong
APPROVED BY: J.Y. Wong

PowerTech Labs Inc.
12388 - 88th Ave.
Surrey, B.C. V3W 7R7

Phone: (604) 590-7500
Fax: (604) 590-5347

Cont-0453



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Lab Mix D	
Client:		Date Cast: 90-11-6	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: D	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
D4	7	90-11-13	100	83.25	9.6
D5	7	90-11-13	100	84.75	9.8
D6	7	90-11-13	100	84.0	9.7
D8	28	90-11-30	100	10.9	10.9
D9	28	90-11-30	100	10.6	10.6
D10	87	91-02-01	100	135.0	15.6
D11	87	91-02-01	100	135.0	15.6
D12	87	91-02-01	100	130.5	15.1

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_____	APPROVED BY: J.Y. Wong

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CSA-904.38



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Lab Mix E	
Client:		Date Cast: 90-11-05	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: E	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
E4	9	90-11-14	100	50.25	5.8
E5	9	90-11-14	100	50.25	5.8
E6	9	90-11-14	100	51.25	6.0
E7	28	90-12-3	100	64.5	7.5
E8	28	90-12-3	100	64.5	7.5
E9	28	90-12-3	100	66.75	7.7
E10	84	91-02-4	100	94.5	10.9
E11	84	91-02-4	100	94.5	10.9
E12	84	91-02-4	100	97.5	11.3

Distribution of Report:

T.Ss

TESTED BY:

J.Y. Wong

APPROVED BY: J.Y. Wong

PowerTech Labs Inc.
12500 - 80th Ave.
Surrey, B.C. V3W 7R7

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CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Lab Mix F	
Client:		Date Cast: 90-11-7	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: F	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
F4	7	90-11-14	100	54.75	6.3
F5	7	90-11-14	100	55.5	6.4
F6	7	90-11-14	100	60.75	7.0
F7	28	90-12-05	100	93.75	10.8
F8	28	90-12-05	100	84.00	9.7
F9	28	90-12-05	100	89.25	10.3
F10	82	91-02-06	100	113.3	13.1
F11	82	91-02-06	100	130.5	15.1
F12	82	91-07-06	100	130.5	15.1

Distribution of Report:

TESTED BY: TSS

APPROVED BY: J.Y. Wong

PowerTech Labs Inc.
12388 - 88th Ave.
Surrey, B.C. V3W 7K7

Phone: (604) 590-7500
Fax: (604) 590-5347

Case-qt.36



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Lab Mix G	
Client:		Date Cast: 90-11-15	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: G	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
G4	7	90-11-22	100	87.75	10.1
G5	7	90-11-22	100	90.75	10.5
G6	7	90-11-22	100	88.5	10.2
G7	7.8	90-12-13	100	123.0	14.2
G8	28	90-12-13	100	127.5	14.7
G9	28	90-12-13	100	126.0	14.6
G10	74	90-12-13	100	126.0	14.6
G11	74	91-02-14	100	183.8	21.2
G12	74	91-02-14	100	187.5	21.7

Distribution of Report:

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TESTED BY:

APPROVED BY: J.Y. Wong

PowerTech Labs Inc.
12308 - 80th Ave.
Surrey, B.C. V3W 7K7

Phone: (604) 590-7500
Fax: (604) 590-5347

CM-001.97



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Shotcrete	
Client: Envirochem		Date Cast: 90-12-7	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: A	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
A1	7	90-12-14	75 x 89	13.5	2.67
A2	7	90-12-14	75 x 95	12.5	2.6
A3	34	91-01-10	75 x 105	21.8	4.6
A4	34	91-01-10	75 x 110	21.0	4.4
A3	91	91-02-28	75 x 86	37.5	7.4
A4	91	91-02-28	75 x 107	39.0	8.2

REMARKS: Cylinders were cored from shotcrete test panels. Results are corrected for length.

Distribution of Report:

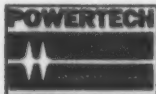
TSS
TESTED BY:

APPROVED BY: J.Y. Wong

Powertech Labs Inc.
12388 - 88th Ave.
Surrey, B.C. V3W 7K7

Phone: (604) 590-7500
Fax: (604) 590-5347

Cons-cyl.38



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Shotcrete	
Client: Envirochem		Date Cast: 90-12-17	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: D	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
D1	7	90-12-14	75 x 150	57	12.15
D2	7	90-12-14	75 x 150	60.75	13.3
D3	34	91-01-10	75 x 150	69.0	15.1
D4	34	91-01-10	75 x 150	66.8	14.6
D5	91	91-02-28	75 x 138	126	26.6
D6	91	91-02-28	75 x 117	124.5	26.9

REMARKS: Results corrected for length

Distribution of Report:

Tss
TESTED BY:

J. Y. Wong
APPROVED BY: J.Y. Wong

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Surrey, B.C. V3W 7K7

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Fax: (604) 590-5347

Gen-0431



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT:	Westmin	Part of Structure:	Shotcrete
Client:	Envirochem	Date Cast:	90-12-7
Contractor:		Concrete Supplier:	
Cast by:	C.S. Gung	Slump:	
Air (specified):		Actual:	Nominal Max. Size Agg.:
Concrete Temp.:		Ambient Temp.:	Mix Des. No.: E
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	CYLINDER SIZE (Diameter x length)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
E1	7	90-12-14	75 x 95	37.5	7.6
E2	7	90-12-14	75 x 98	36.0	7.4
E3	34	91-01-10	75 x 111	63.0	13.2
E4	34	91-01-10	75 x 112	65.3	13.7
E5	91	91-02-28	75 x 113	82.5	17.4
E6	91	91-02-28	75 x 114	87	18.4

REMARKS: Results corrected for length

Distribution of Report:

TSS
TESTED BY:


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Cont-cyl.53



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Shotcrete	
Client:		Date Cast: 90-12-7	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: F	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
F1	7	90-12-7	75 x 150	10.5	2.3
F2	7	90-12-7	75 x 146	11.25	2.5
F3	34	91-01-10	75 x 138	36.8	8.9
F4	34	91-01-10	75 x 148	36.8	8.9
F5	91	91-02-28	75 x 133	38.8	8.4
F6	91	91-02-28	75 x 103	39.3	7.9

REMARKS: Results corrected for length

Distribution of Report:

TESTED BY:

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Cons-0453



CONCRETE CYLINDER REPORT
CAN/CSA-A23.2-9C M904

PROJECT: Westmin		Part of Structure: Shotcrete	
Client:		Date Cast: 90-12-7	
Contractor:		Concrete Supplier:	
Cast by: C.S. Gung		Slump:	
Air (specified):	Actual:	Nominal Max. Size Agg.:	
Concrete Temp.:	Ambient Temp.:	Mix Des. No.: G	
Specified Strength at 28 days:		Date Received in Laboratory:	

LAB NO.	AGE, (days)	DATE TESTED	AVERAGE DIAMETER, (mm)	BREAKING LOAD, (kN)	COMPRESSIVE STRENGTH, (MPa)
G1	7	90-12-14	75 x 108	27	5.6
G2	7	90-12-14	75 x 98	24	5.1
G3	34	91-01-10	75 x 111	48	10.1
G4	34	91-01-10	75 x 112	42	8.8
G5	91	91-03-01	75 x 79	67.5	13.1
G6	91	91-03-01	75 x 79	67.5	13.1

REMARKS: Results corrected for length

Distribution of Report:

TESTED BY:

APPROVED BY: J.Y. Wong

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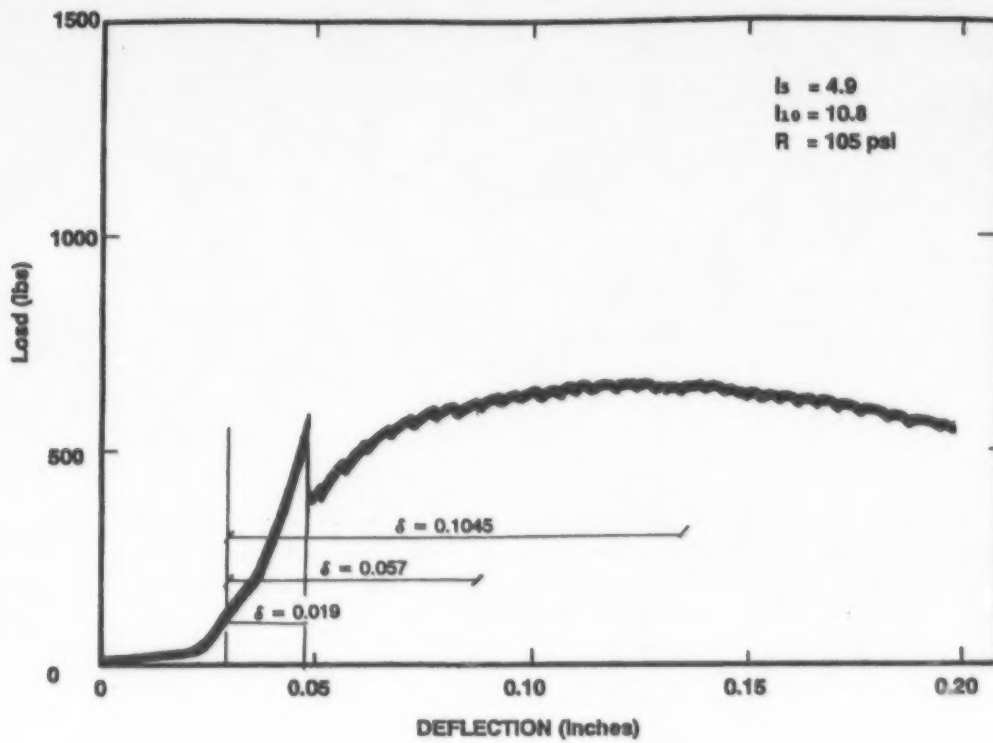
Phone: (604) 590-7500
Fax: (604) 590-5347

CMC-9134

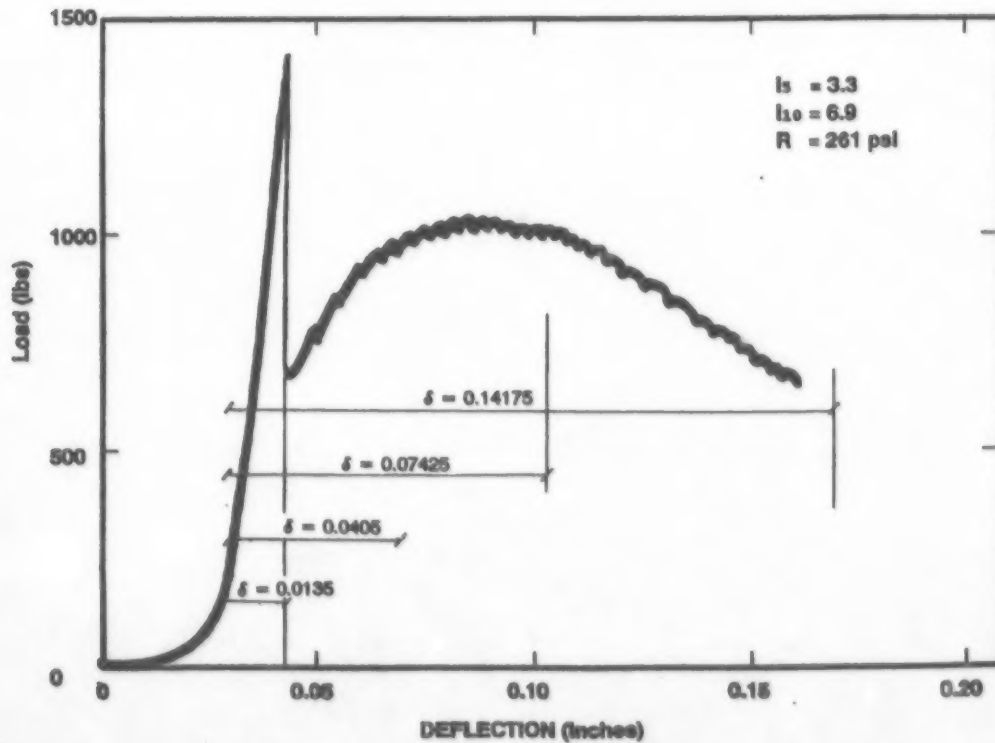
APPENDIX C

FLEXURAL TOUGHNESS TESTS

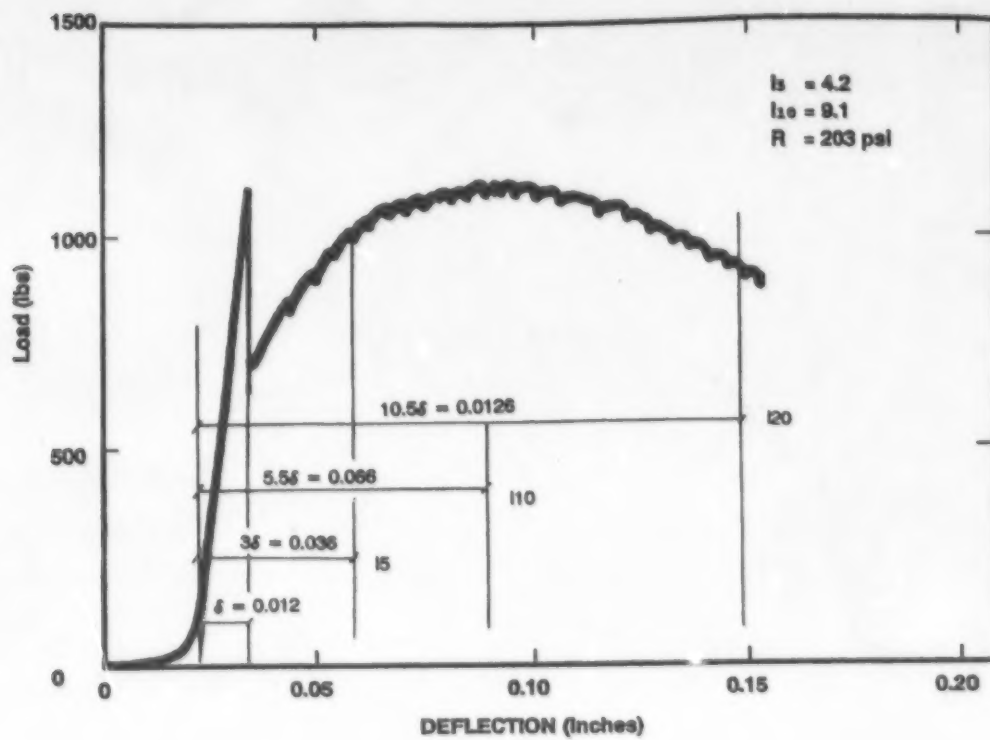
SHOTCRETE A - 7 day cure



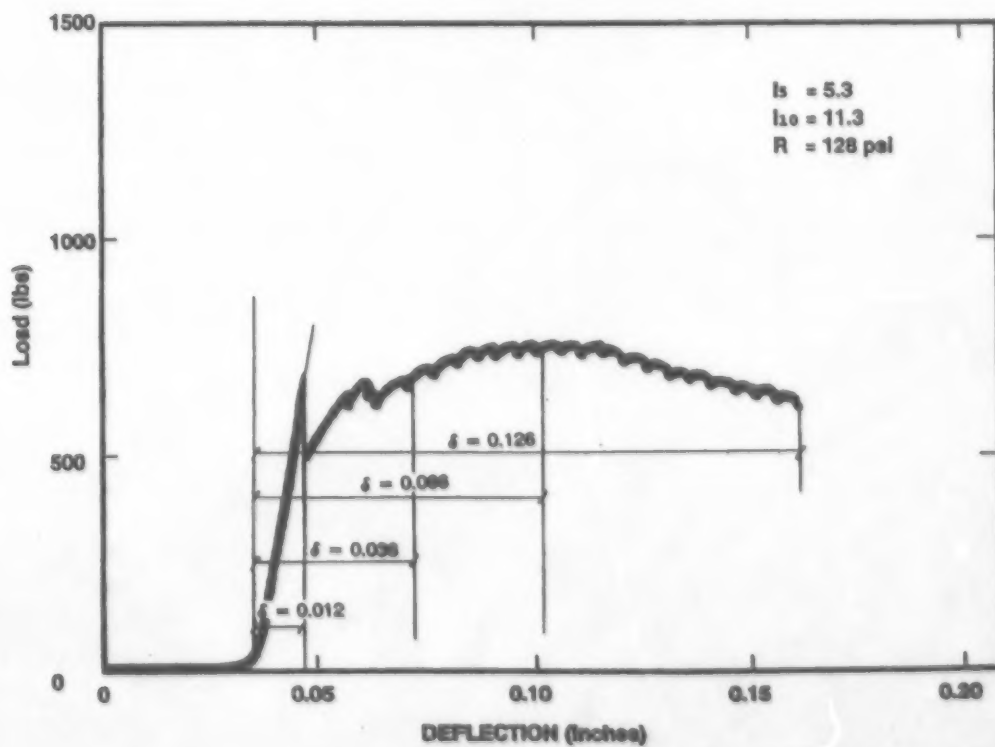
SHOTCRETE D - 7 day cure



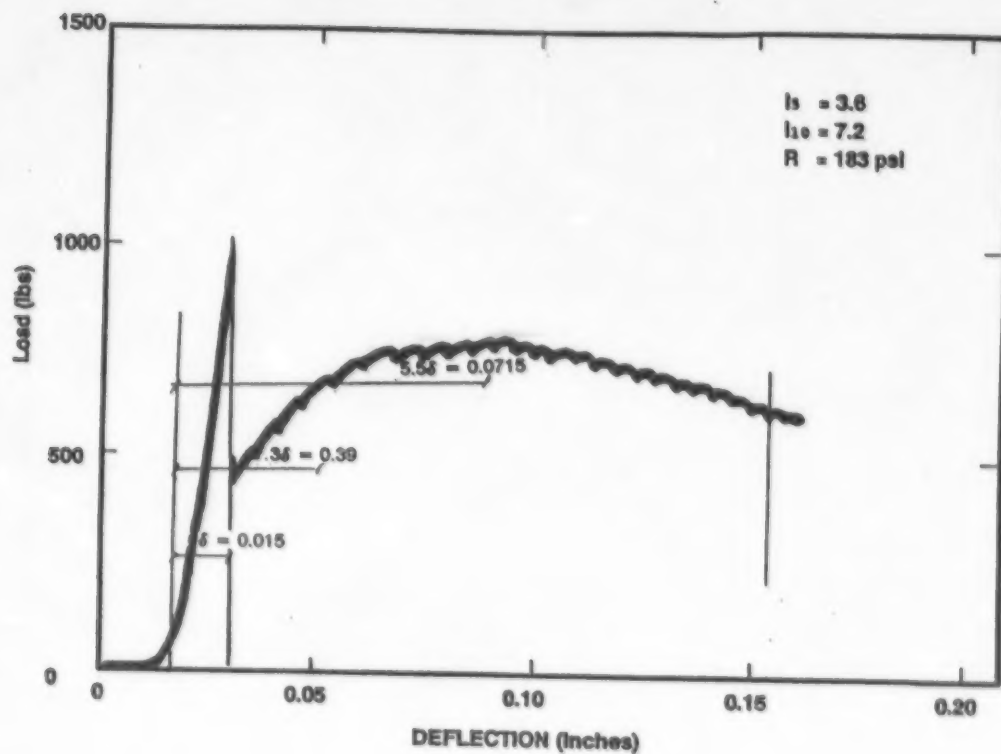
SHOTCRETE E - 7 day cure



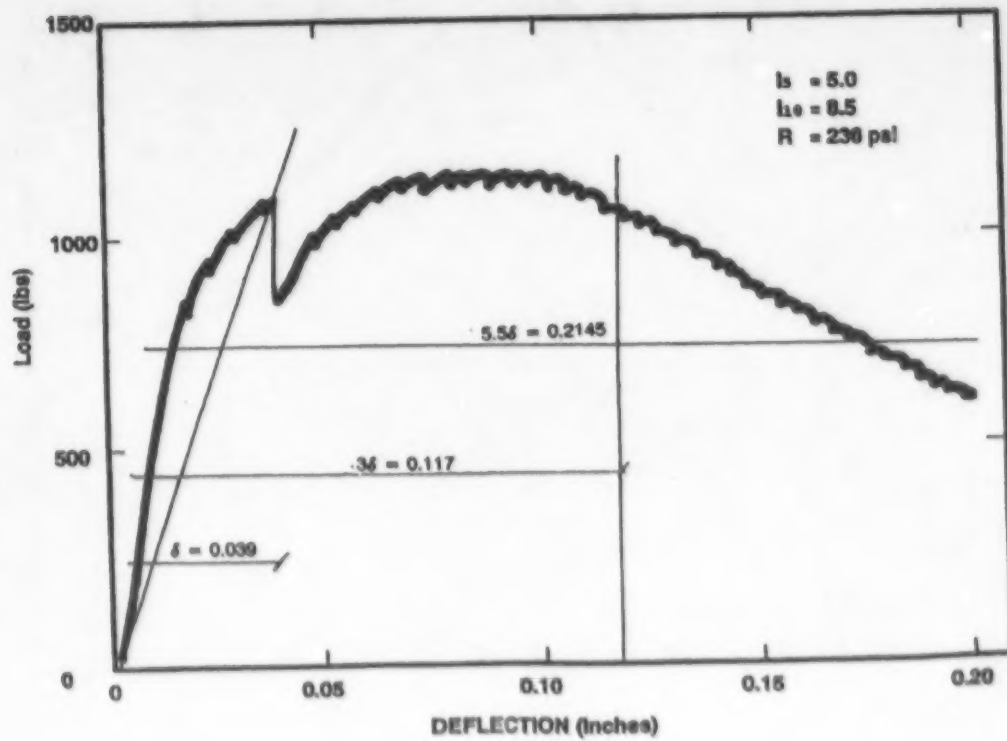
SHOTCRETE F - 7 day cure



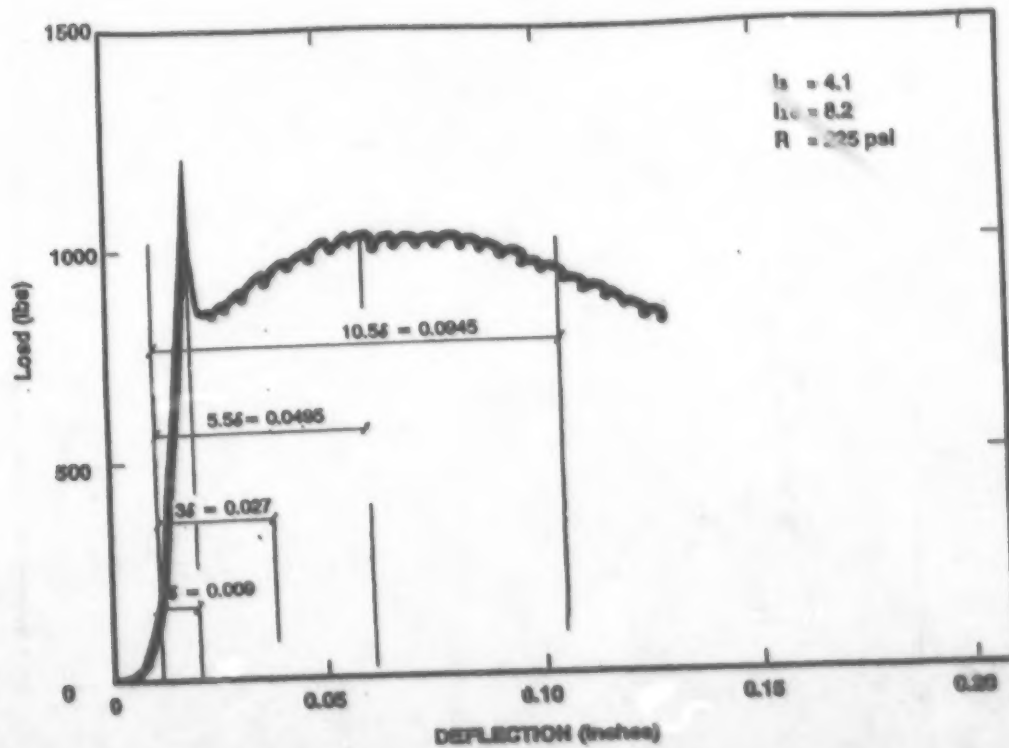
SHOTCRETE G - 7 day cure



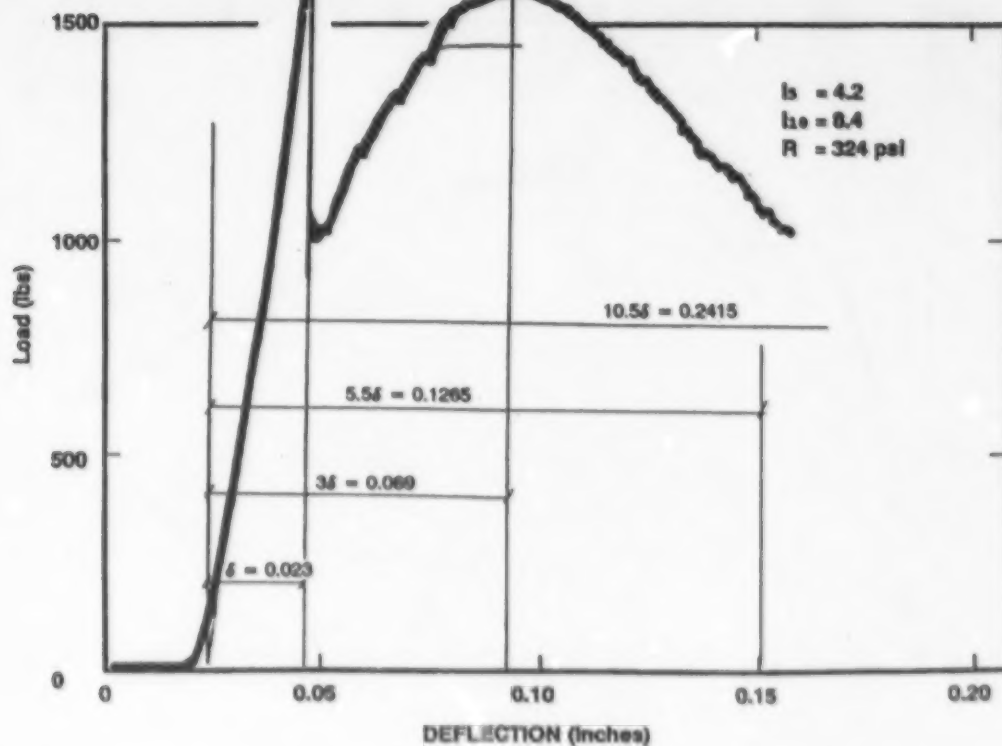
SHOTCRETE A - 32 day cure



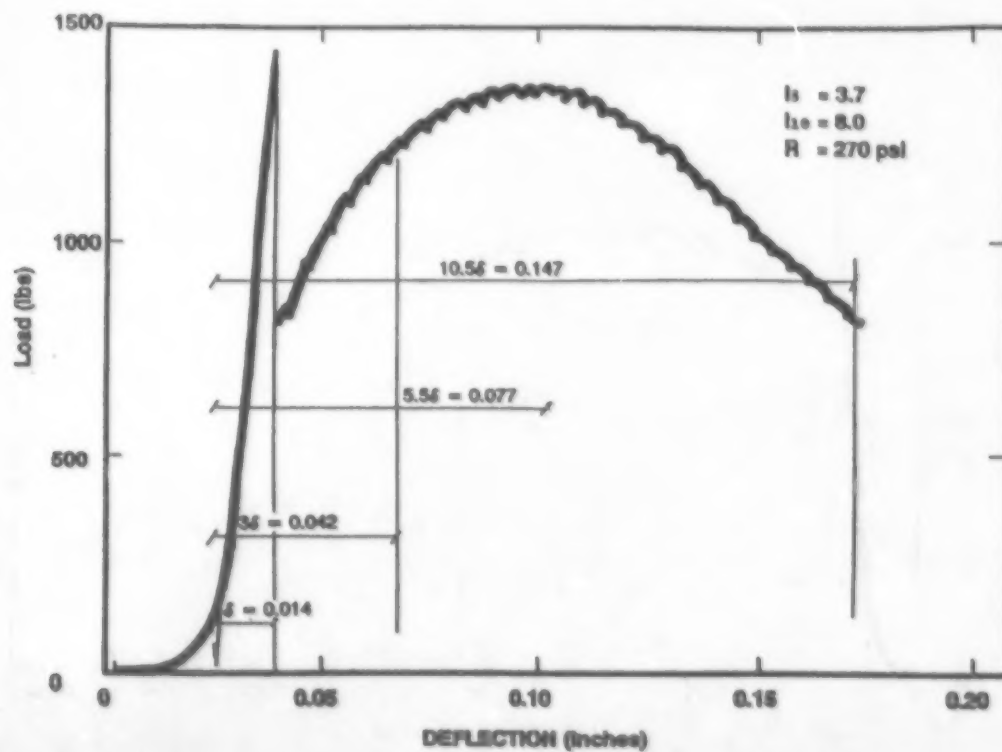
SHOTCRETE D - 33 days cure



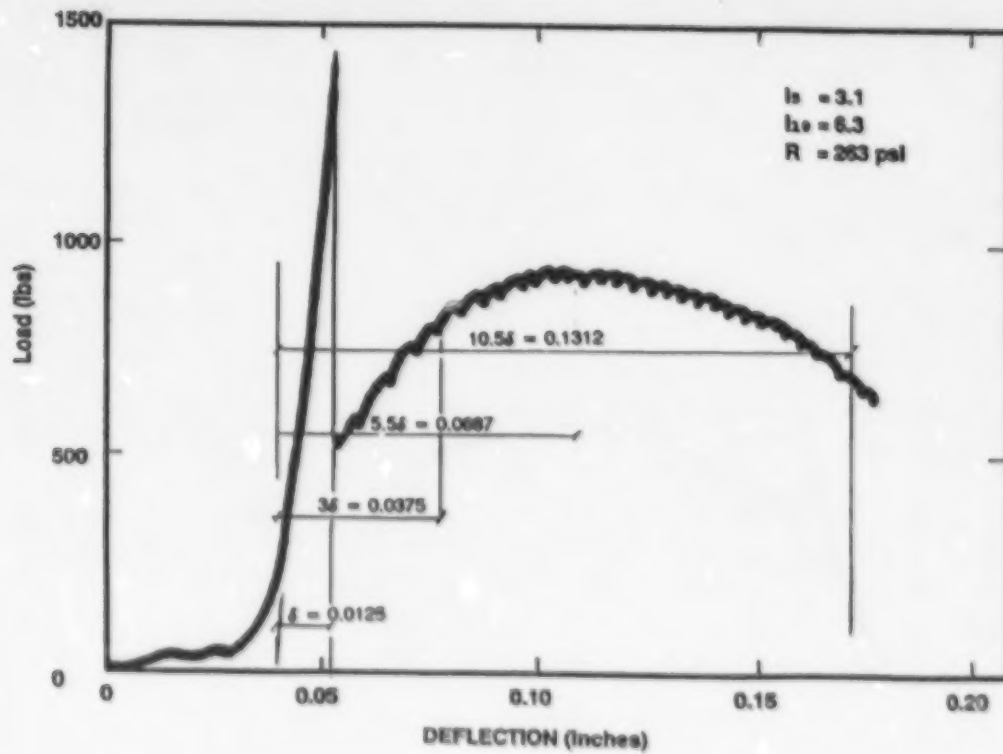
SHOTCRETE E - 33 days cure



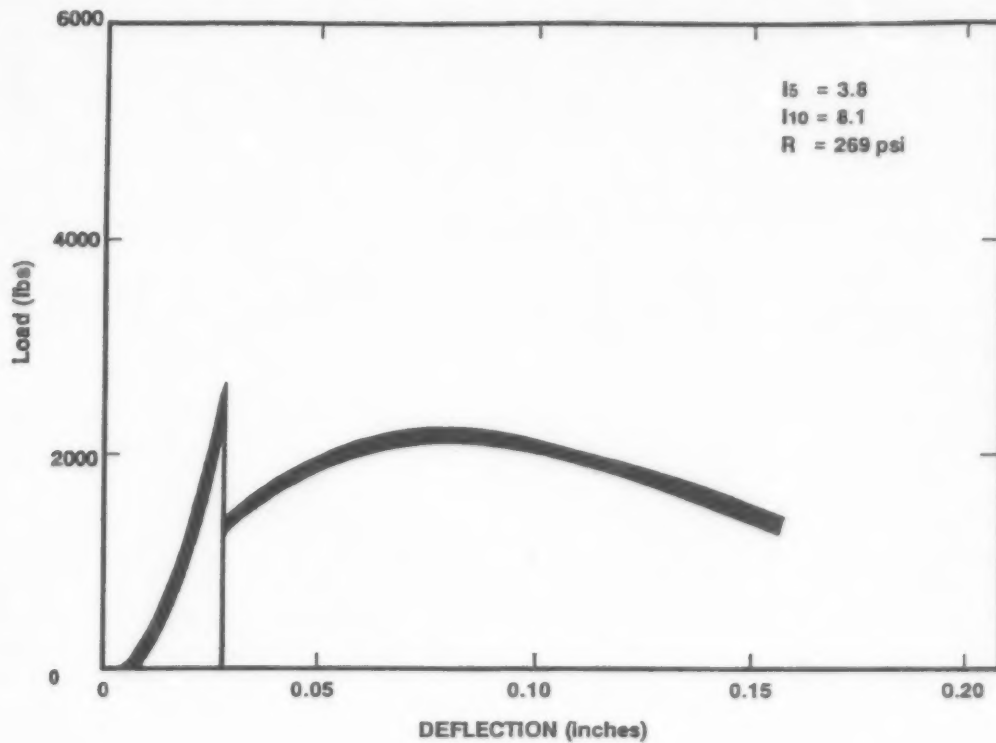
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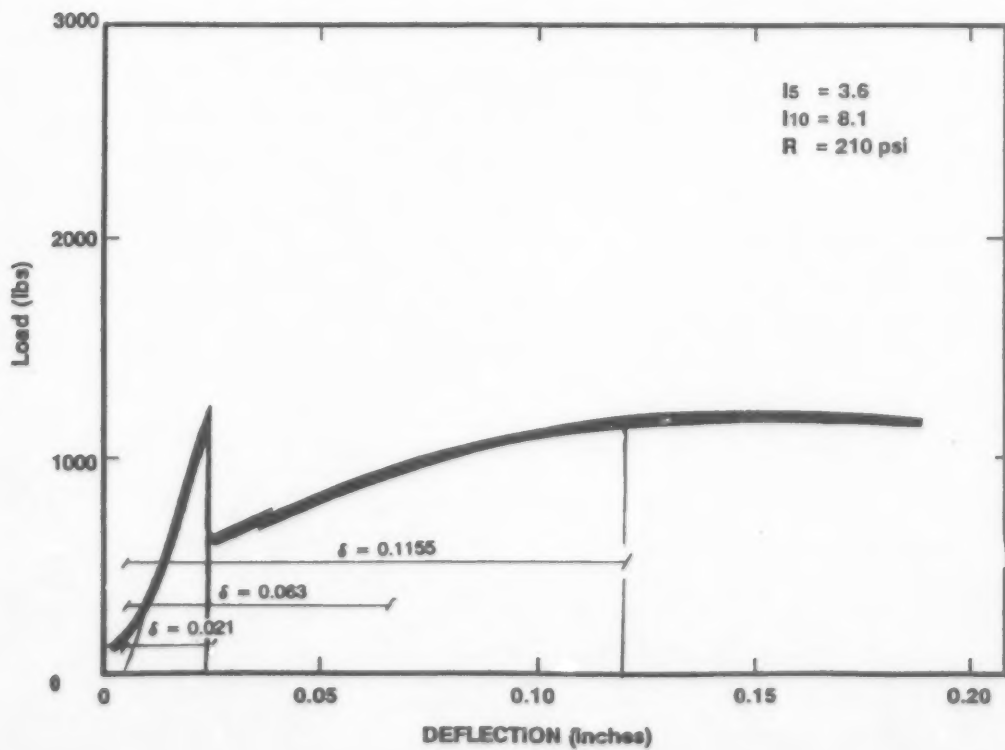
SHOTCRETE G - 33 days cure



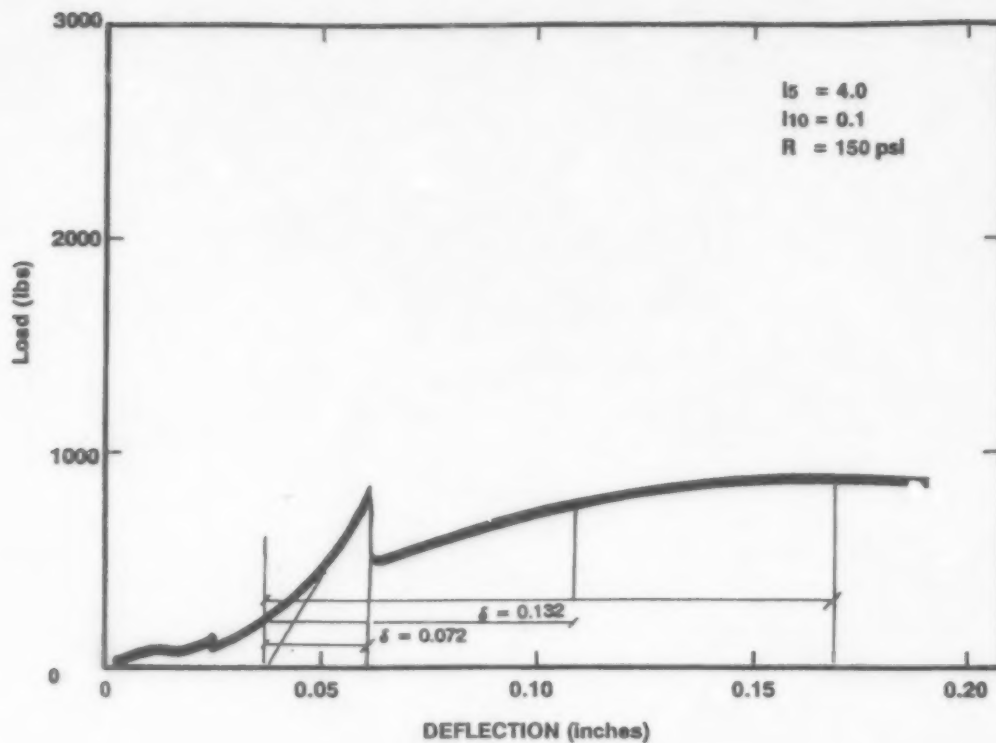
LAB MIX A - 28 days cure



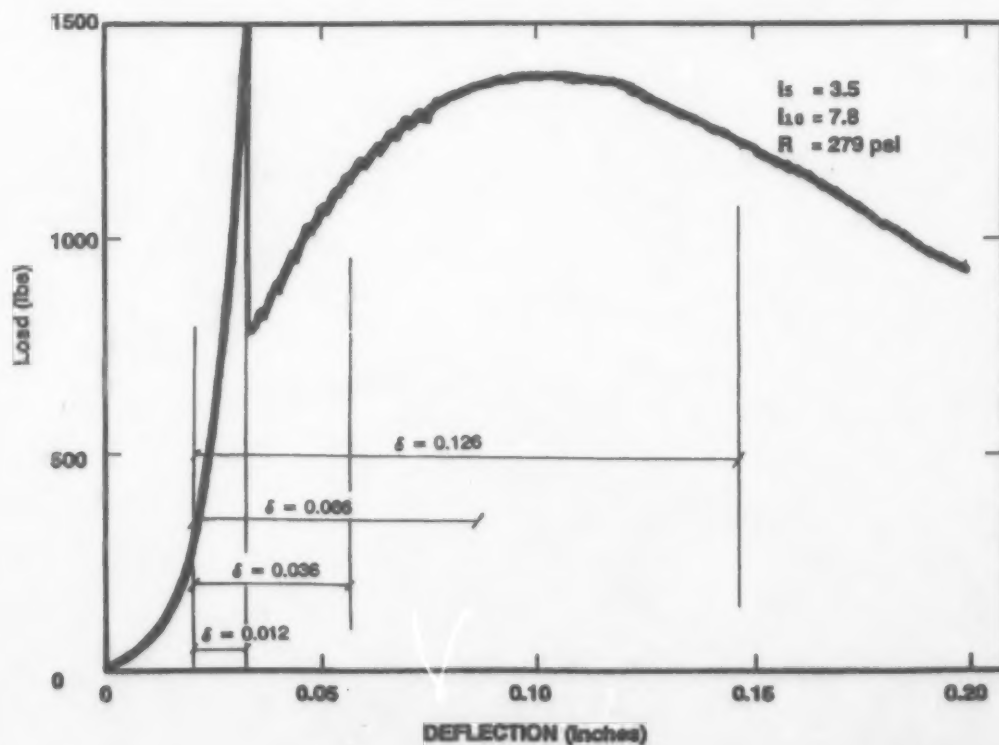
LAB MIX D - 28 days cure



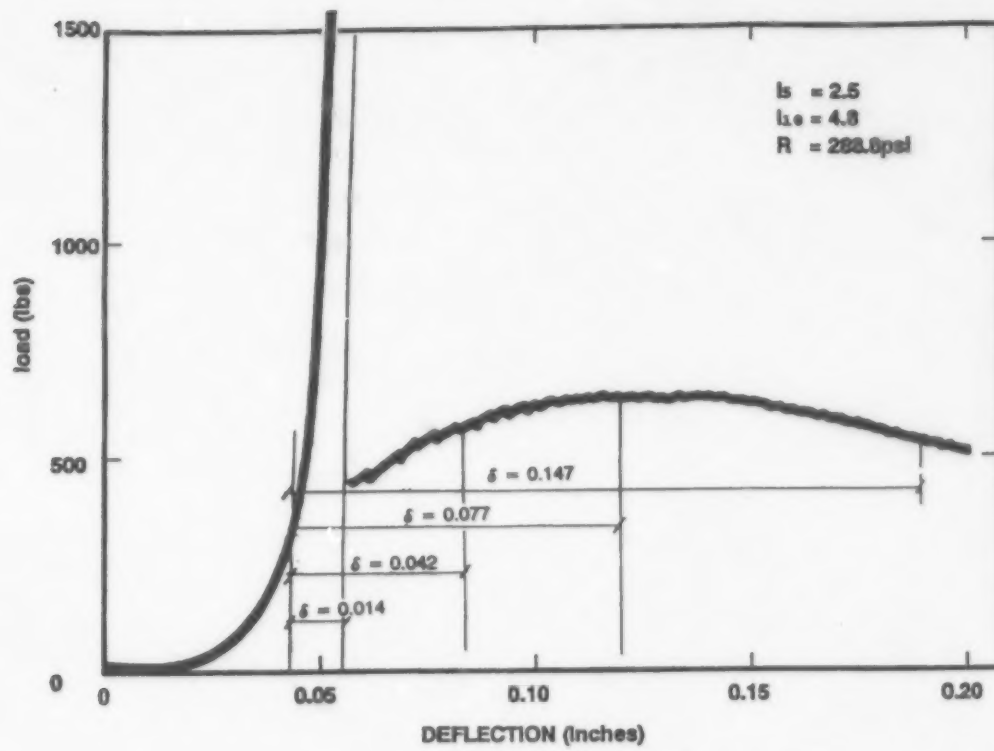
LAB MIX E - 28 days cure



LAB MIX F - 35 days cure



LAB. MIX 'G' - 28days



Vern A. Burkhardt
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